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B32Y B331 B339 B33X
B347 B349 B34Y B357
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B365 B367 B36X B37Y
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B665 B667 B669 B66X
B66Y B670
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GB 1370452
GB 1282334
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(54) A cast bar of an aluminum alloy for wrought products, having improved mechanical properties and workability

(57) The continuously cast bar of aluminum base alloys is of homogeneous structure; is free of defects; exhibits excellent mechanical properties, and; can be subjected, as cast or after a heat treatment, to a working opertion such as forging. Casting is conducted so that solidification speeds of 15°C/sec. and above are achieved. A critical value of the secondary dendrite arm spacing (DAS) and a critical value of the size of second phase particles and/or the grain diameter, which critical values are substantially lower than those in the conventional aluminum alloy ingot, are responsible for fine cast structure capable of remarkably enhancing the workability and the mechanical properties of the aluminum base alloys having the following compositions:–

AA 2000 series alloy: 0.2–9.0% Cu; 0.2–1.2% Mg; 0.2–1.2% Si; 0.2–8% Mn, and the balance Al.

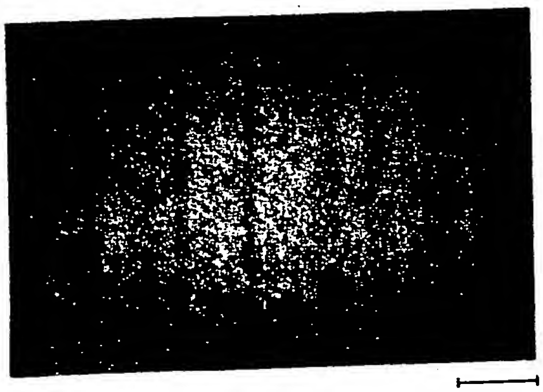
AA 5000 series alloy: 2.0–6.0% Mg; 0.03–0.3% Cr, and; balance Al.

AA 4000 Al–Si–Mg series alloy: 4–12% Si; 0.6–1.3% Mg, and; balance Al.

AA 4000 Al–Si–Cu–Mg series alloy: 2–12% Si; 1.5–5.0% Cu; 0.8–1.3% Mg, and balance Al.

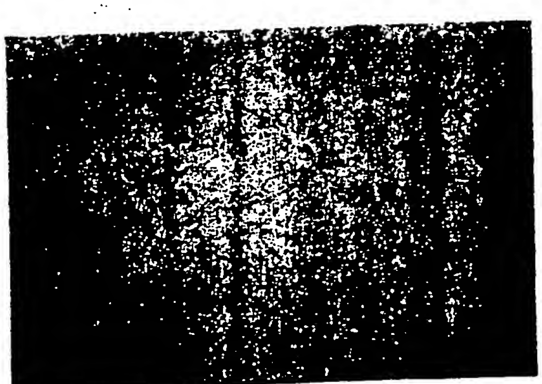
The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

Fig. 1



100 μm

Fig. 2



100 μm

Fig. 3

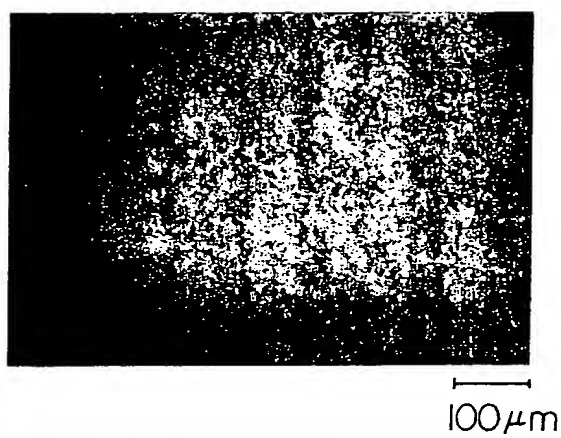


Fig. 4

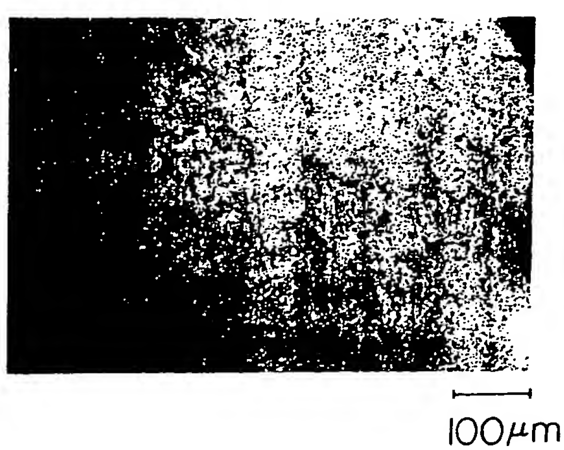


Fig. 5

Fig. 6

2065516

4/20

Fig. 7

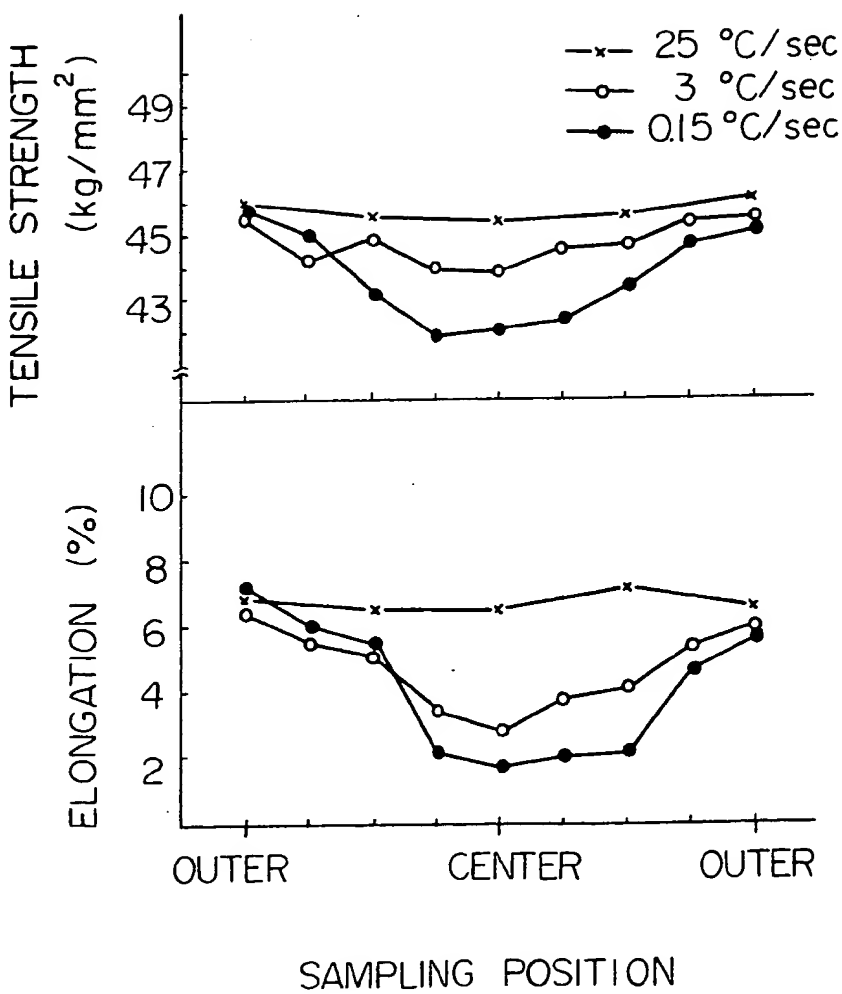


Fig. 8A

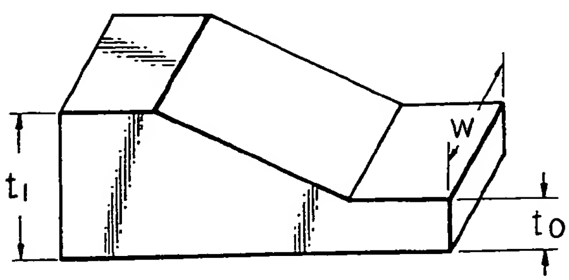


Fig. 8B

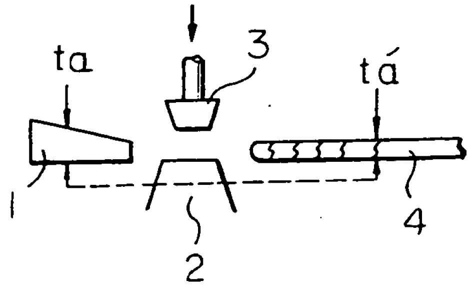


Fig. 9

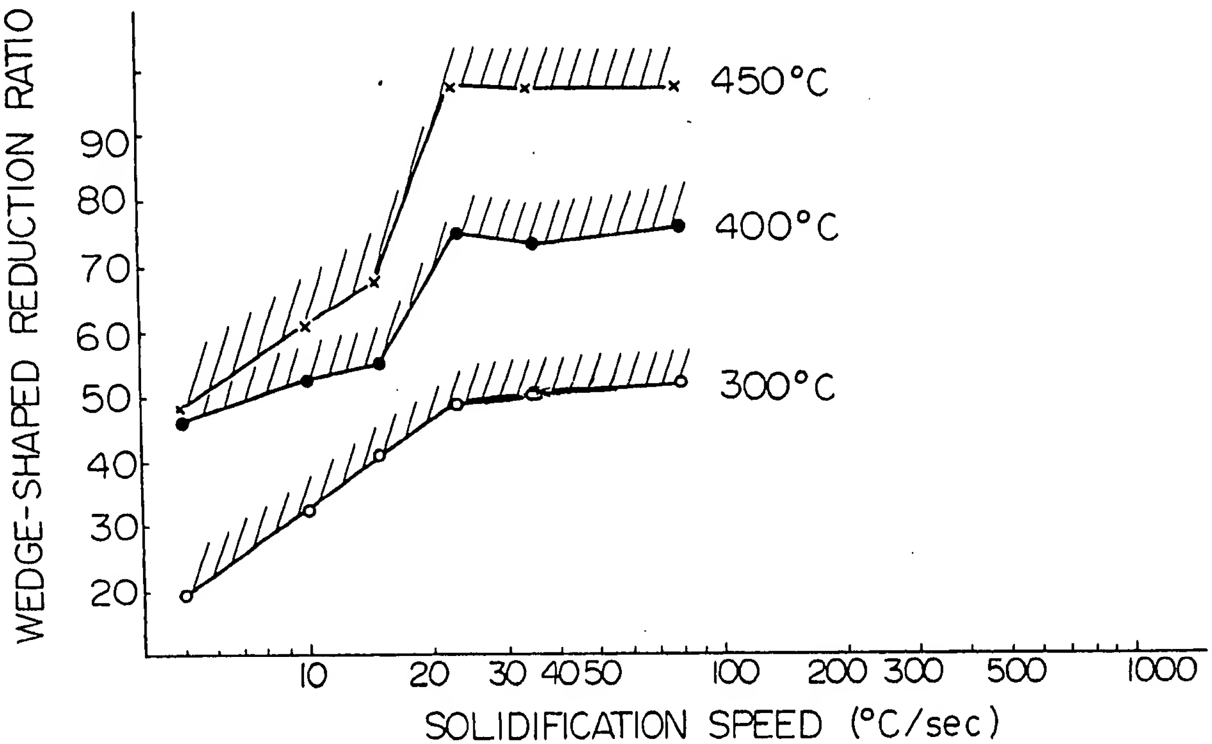

WEDGE-SHAPED REDUCTION RATIO (%)
90
80
70
60
50
40
30
20
450°C
400°C
300°C
10
20
30
40
50
100
200
300
500
1000
SOLIDIFICATION SPEED (°C/sec)

Fig. 10

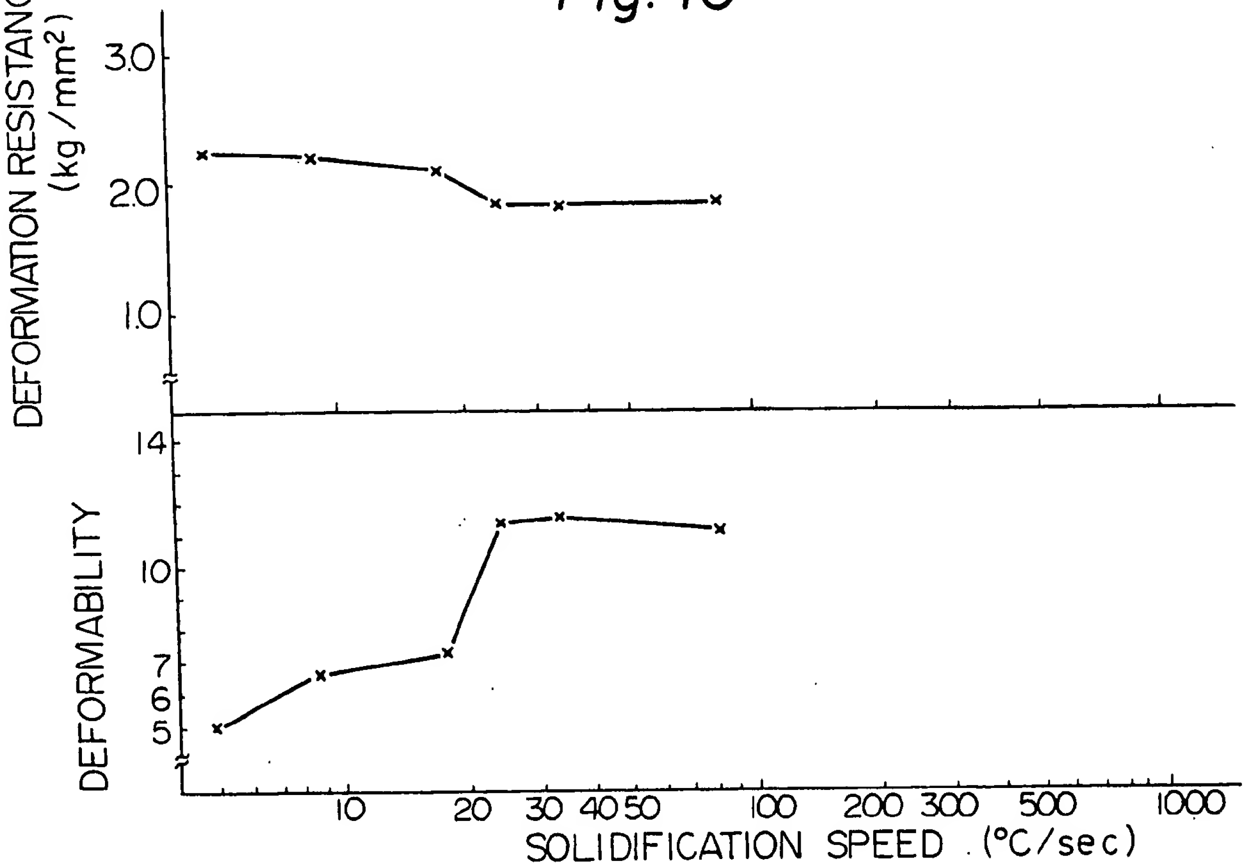
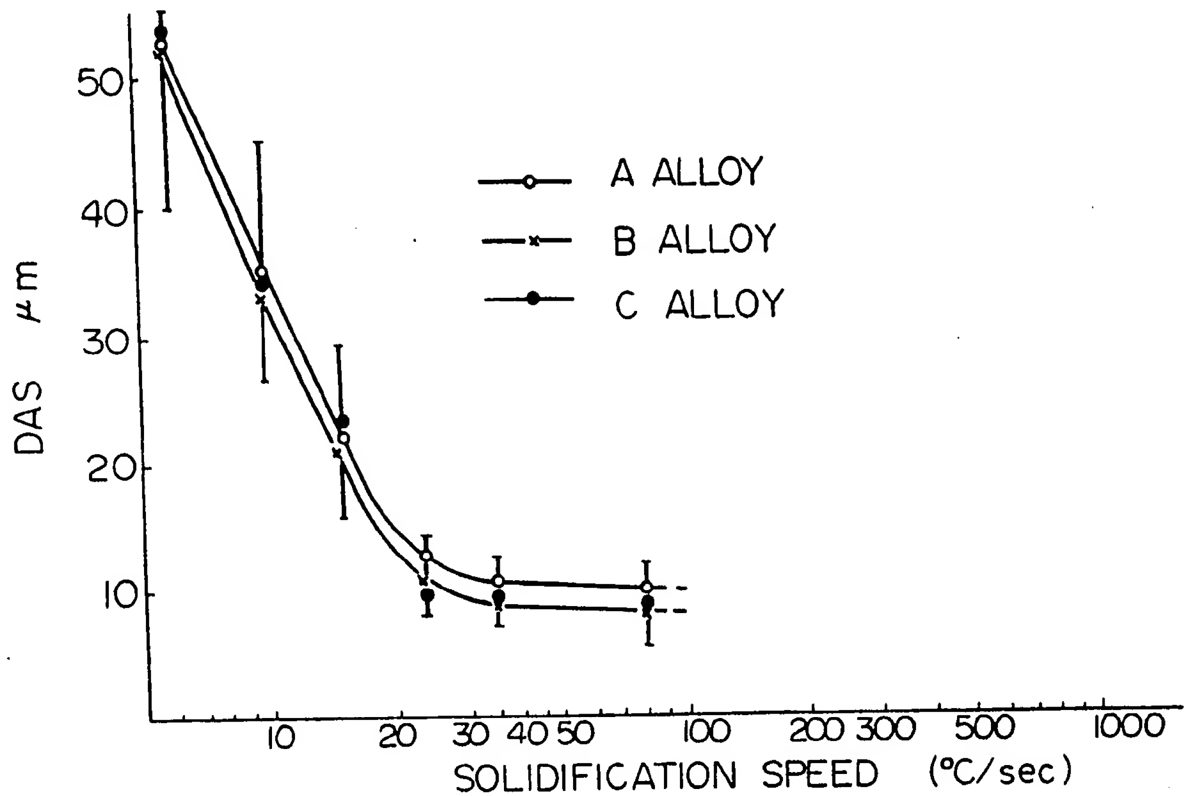

DEFORMATION RESISTANCE (kg / mm²)
3.0
2.0
1.0
DEFORMABILITY
14
10
7
6
5
10
20
30
40
50
100
200
300
500
1000
SOLIDIFICATION SPEED (°C/sec)

Fig. 11


A ALLOY
B ALLOY
C ALLOY
DAS μm
50
40
30
20
10
10
20
30
40
50
100
200
300
500
1000
SOLIDIFICATION SPEED (°C/sec)

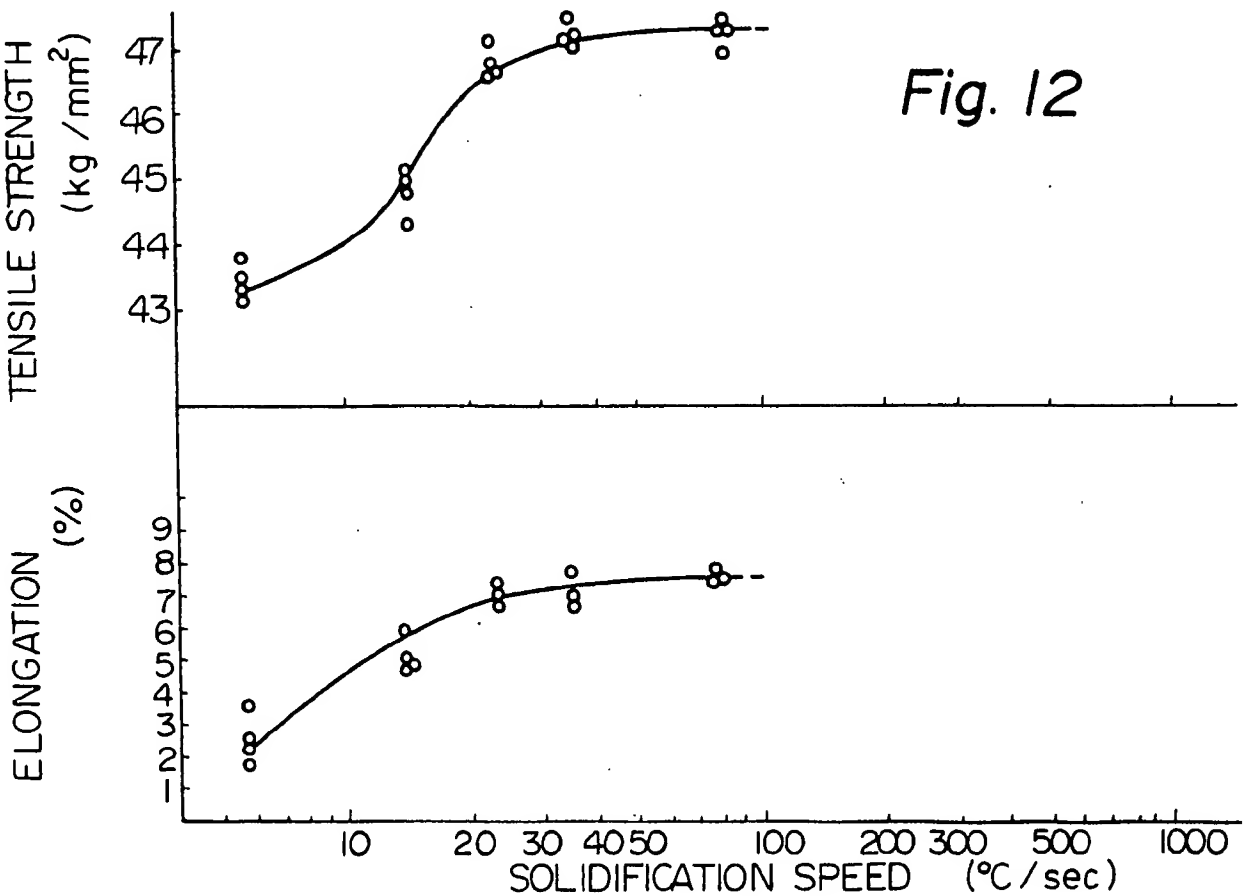

TENSILE STRENGTH (kg/mm²)
47
46
45
44
43
ELONGATION (%)
9
8
7
6
5
4
3
2
1
10
20
30
40
50
100
200
300
500
1000
SOLIDIFICATION SPEED (°C/sec)

Fig. 12

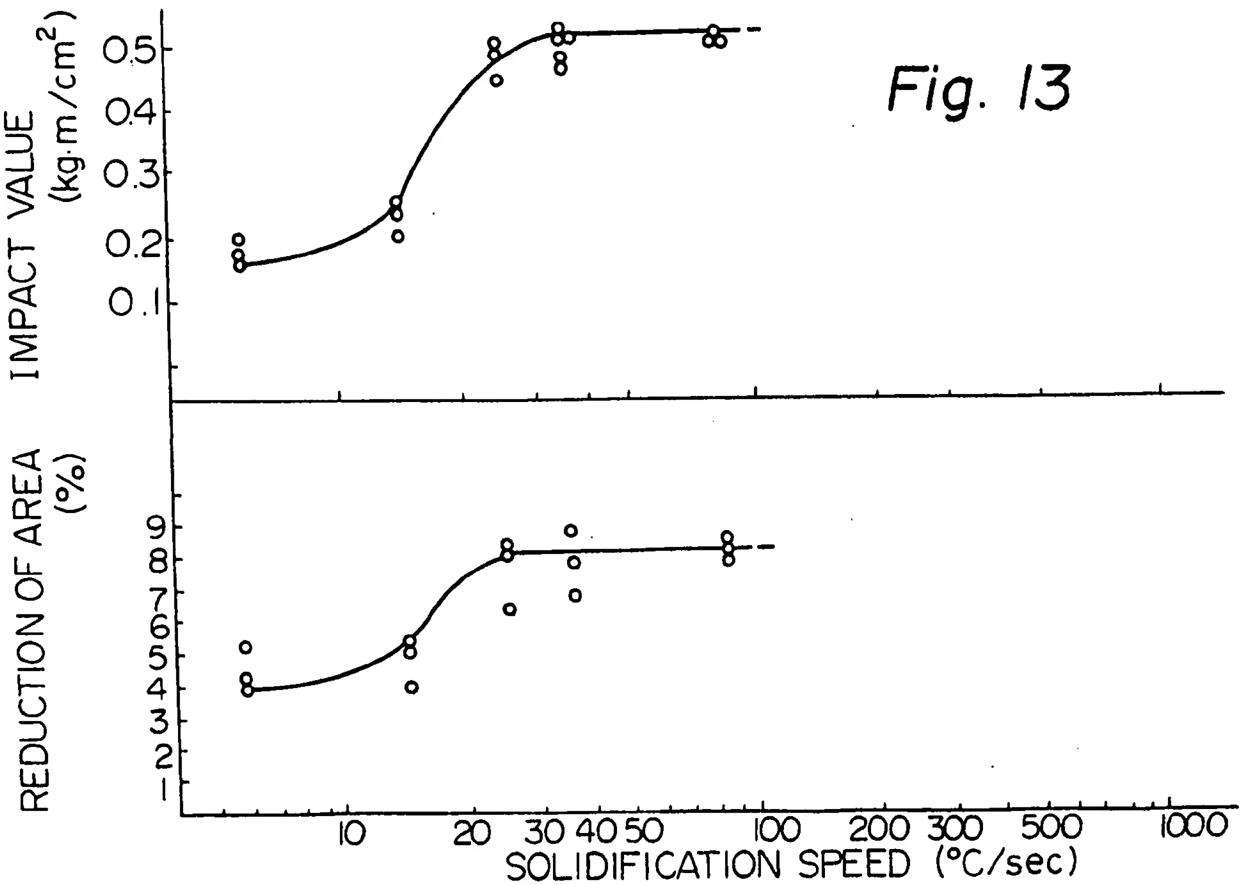

IMPACT VALUE (kg·m/cm^2)
0.5
0.4
0.3
0.2
0.1
REDUCTION OF AREA (%)
9
8
7
6
5
4
3
2
1
10
20
30
40
50
100
200
300
500
1000
SOLIDIFICATION SPEED (°C/sec)

Fig. 13

Fig. 14

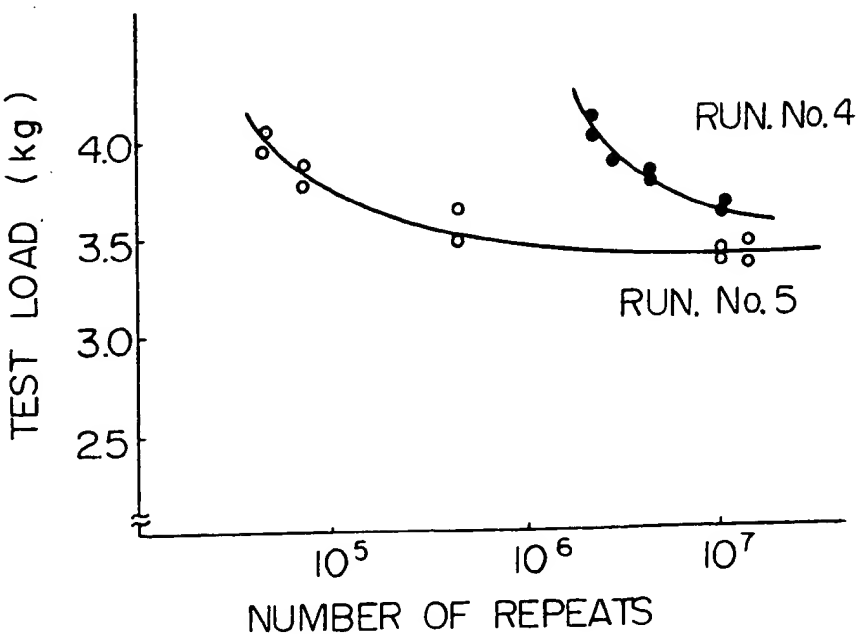

TEST LOAD (kg)
4.0
3.5
3.0
2.5
RUN. No. 4
RUN. No. 5
10^5
10^6
10^7
NUMBER OF REPEATS

Fig. 15

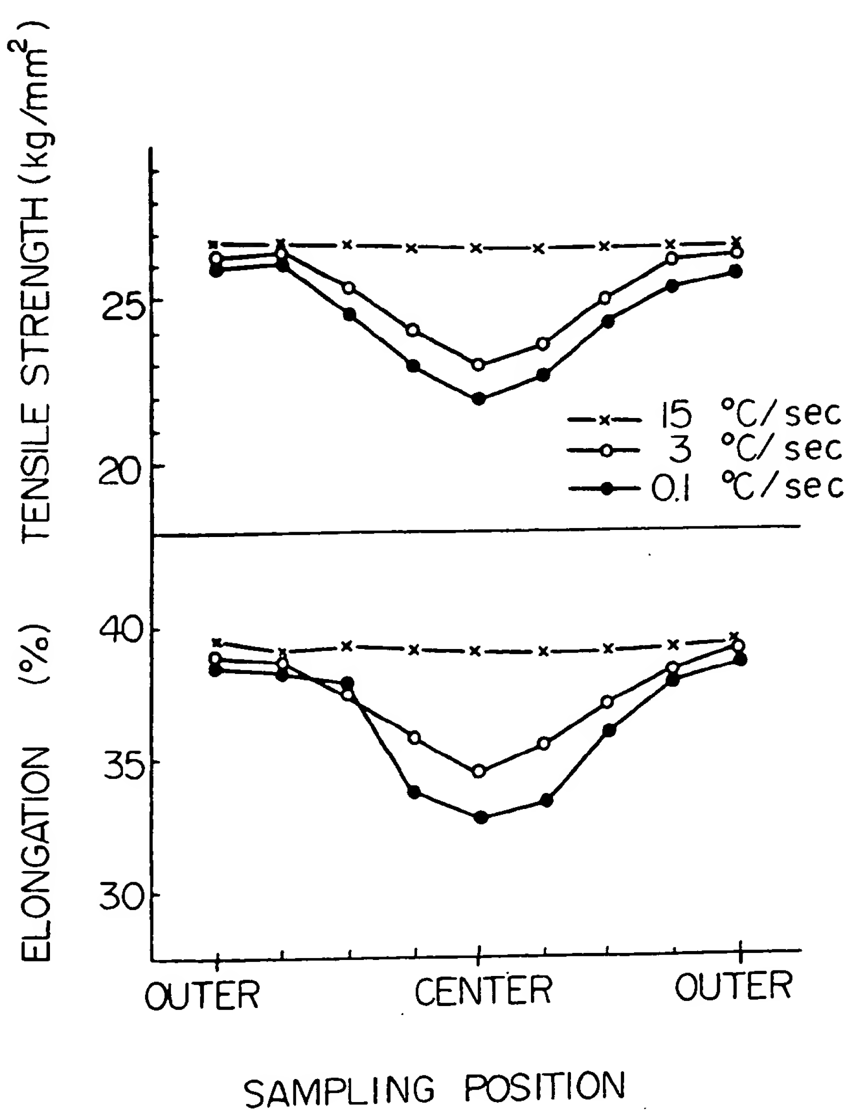

TENSILE STRENGTH (kg/mm²)
25
20
15 °C/sec
3 °C/sec
0.1 °C/sec
ELONGATION (%)
40
35
30
OUTER
CENTER
OUTER
SAMPLING POSITION

Fig. 16

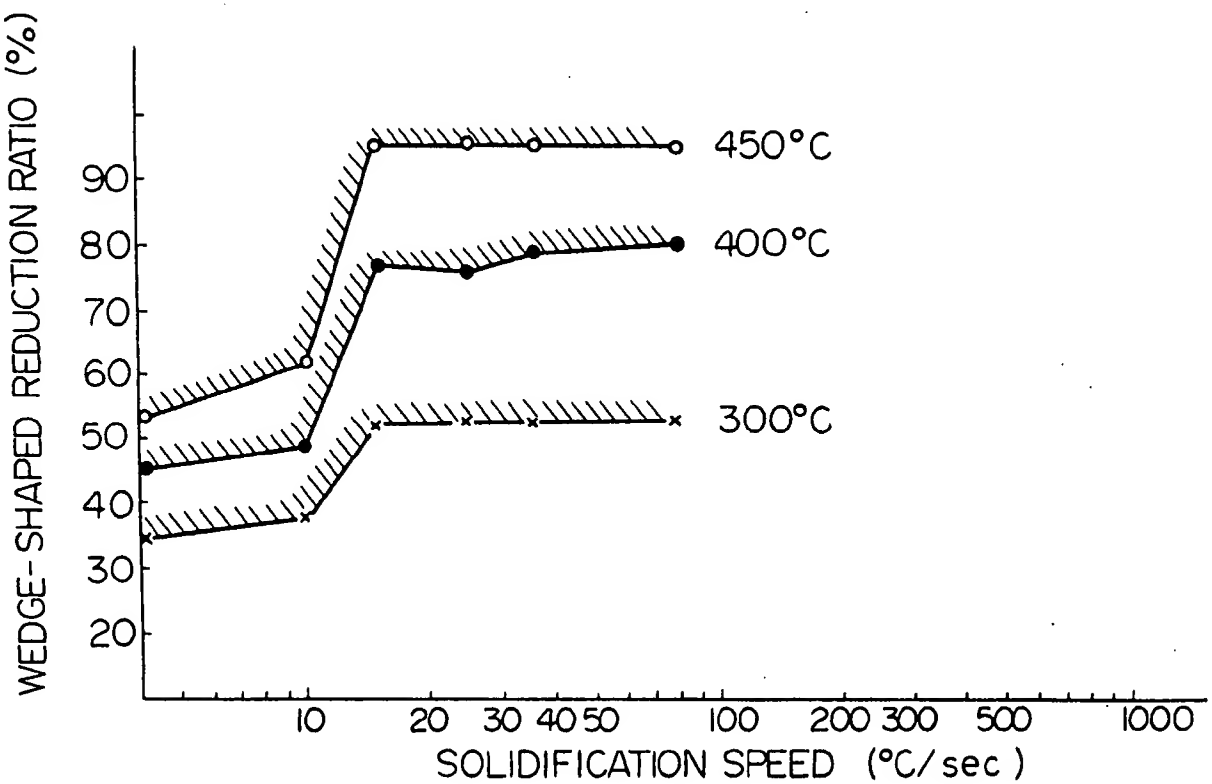
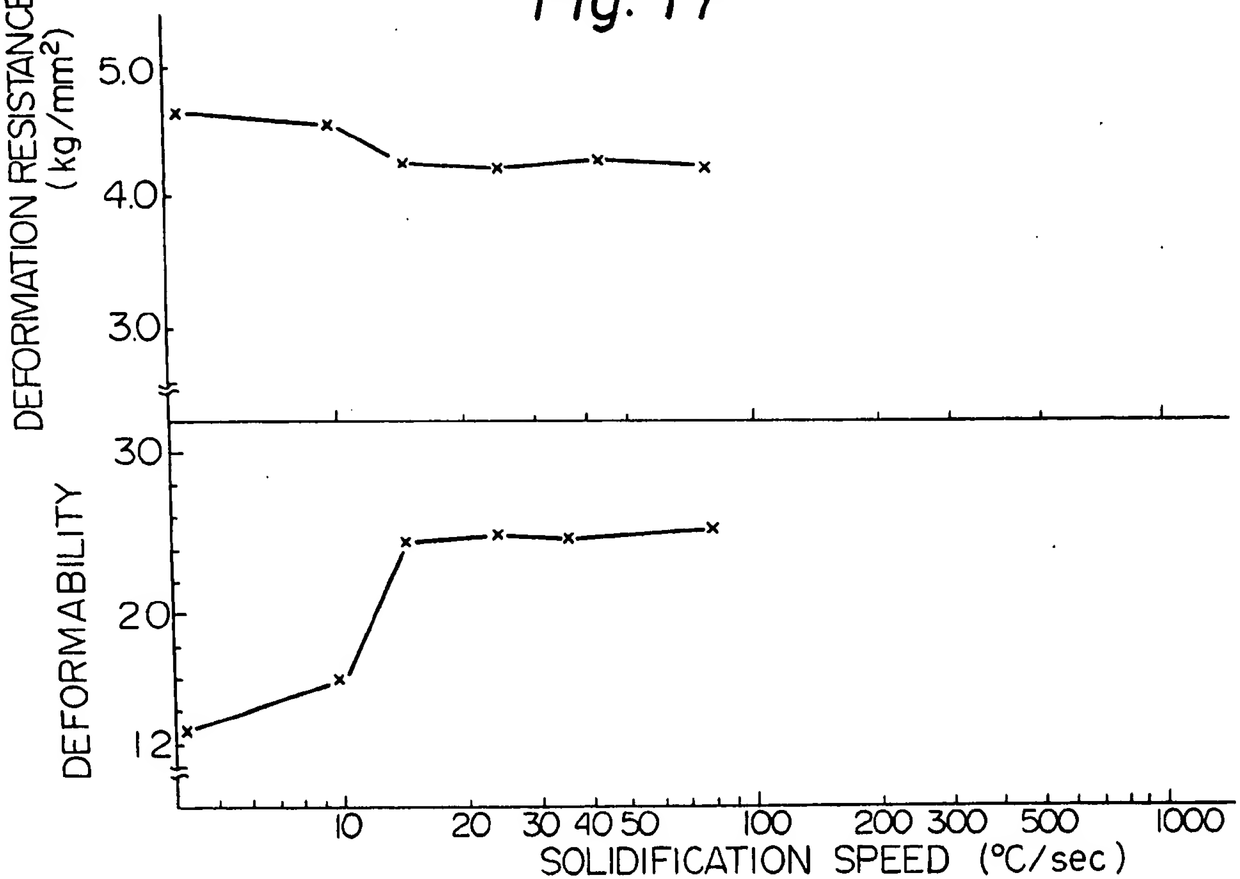

WEDGE-SHAPED REDUCTION RATIO (%)
90
80
70
60
50
40
30
20
450°C
400°C
300°C
10
20
30
40
50
100
200
300
500
1000
SOLIDIFICATION SPEED (°C/sec)

Fig. 17


DEFORMATION RESISTANCE (kg/mm²)
5.0
4.0
3.0
DEFORMABILITY
30
20
12
10
20
30
40
50
100
200
300
500
1000
SOLIDIFICATION SPEED (°C/sec)

2065516

15/20

Fig. 18

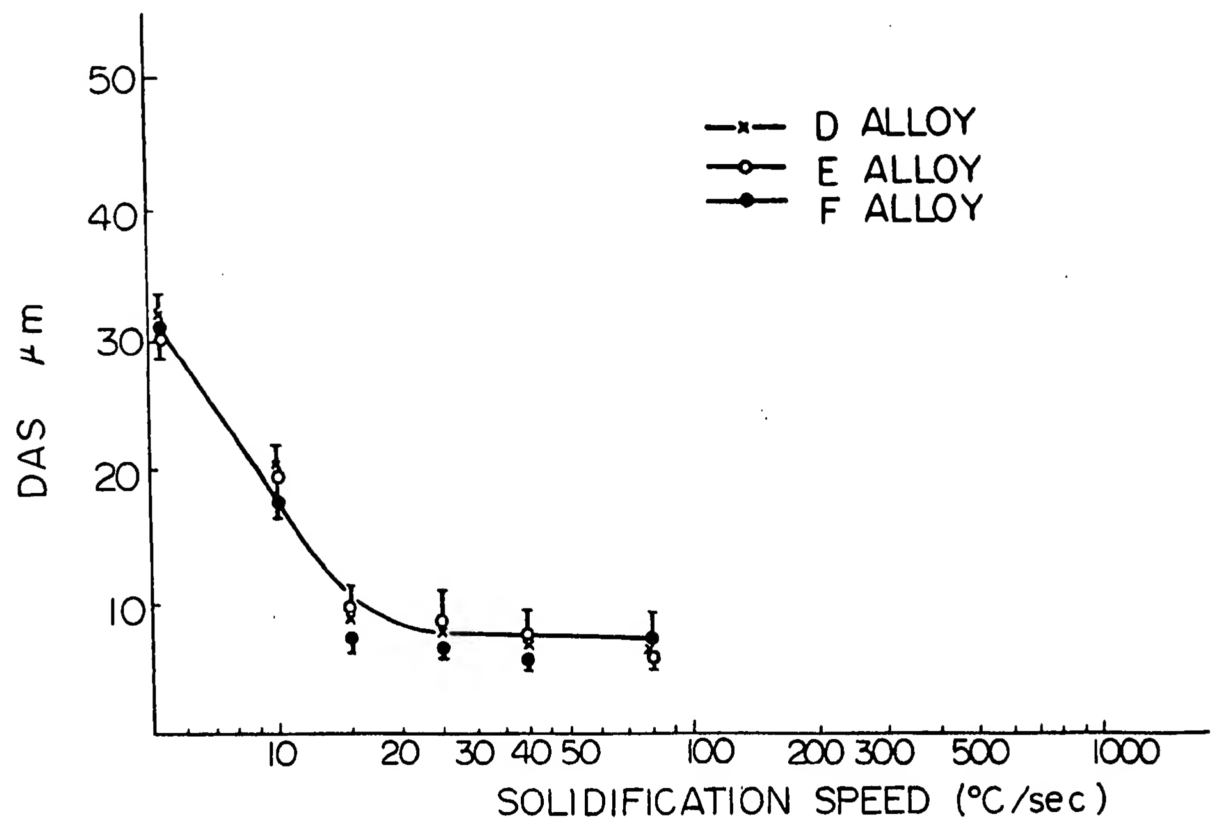


Fig. 19

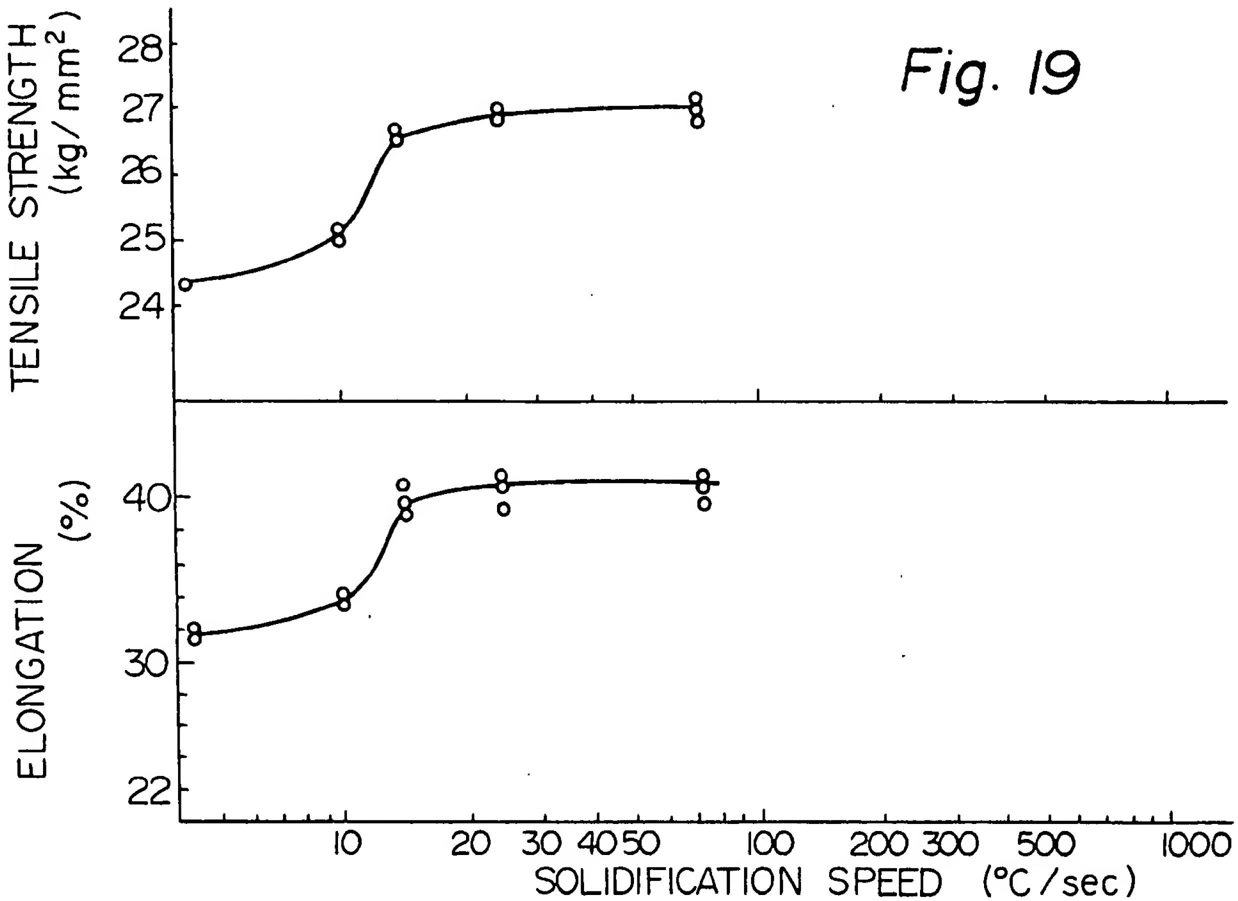

TENSILE STRENGTH (kg/mm²)
28
27
26
25
24
ELONGATION (%)
40
30
22
10
20
30
40
50
100
200
300
500
1000
SOLIDIFICATION SPEED (°C/sec)

Fig. 20

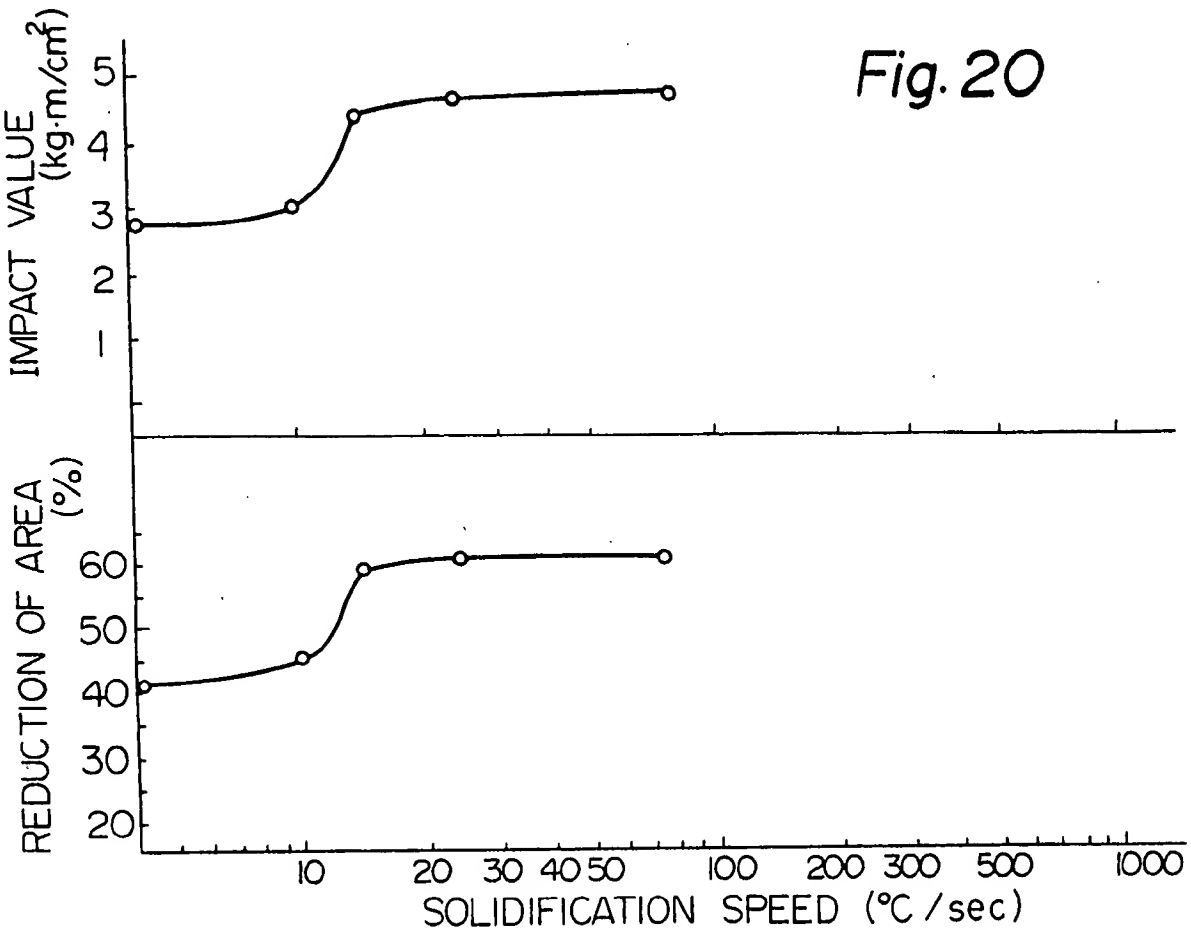

IMPACT VALUE (kg·m/cm²)
5
4
3
2
1
REDUCTION OF AREA (%)
60
50
40
30
20
10
20
30
40
50
100
200
300
500
1000
SOLIDIFICATION SPEED (°C/sec)

Fig. 21

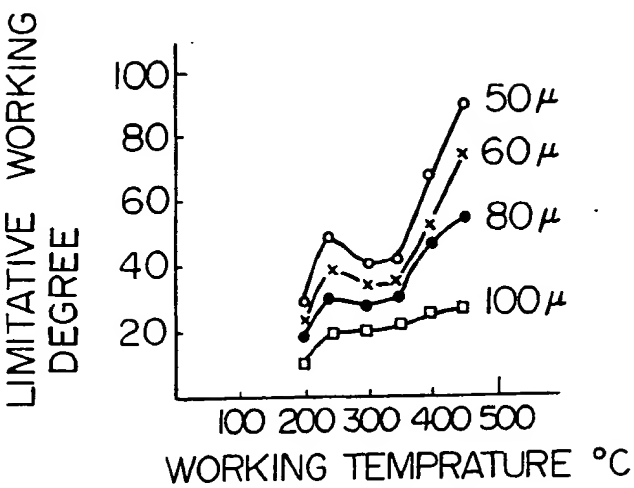

LIMITATIVE WORKING DEGREE
100
80
60
40
20
50μ
60μ
80μ
100μ
100 200 300 400 500
WORKING TEMPRATURE °C

Fig. 23

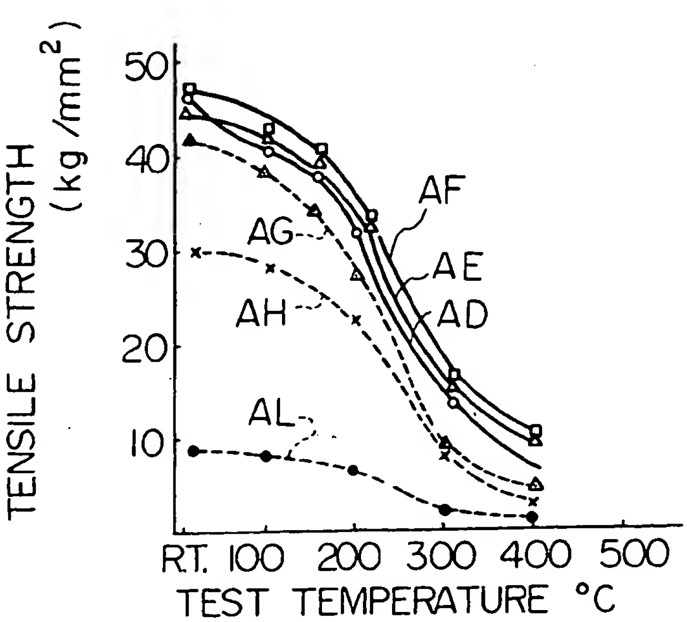

TENSILE STRENGTH (kg/mm²)
50
40
30
20
10
AF
AG
AE
AH
AD
AL
R.T. 100 200 300 400 500
TEST TEMPERATURE °C

Fig. 22

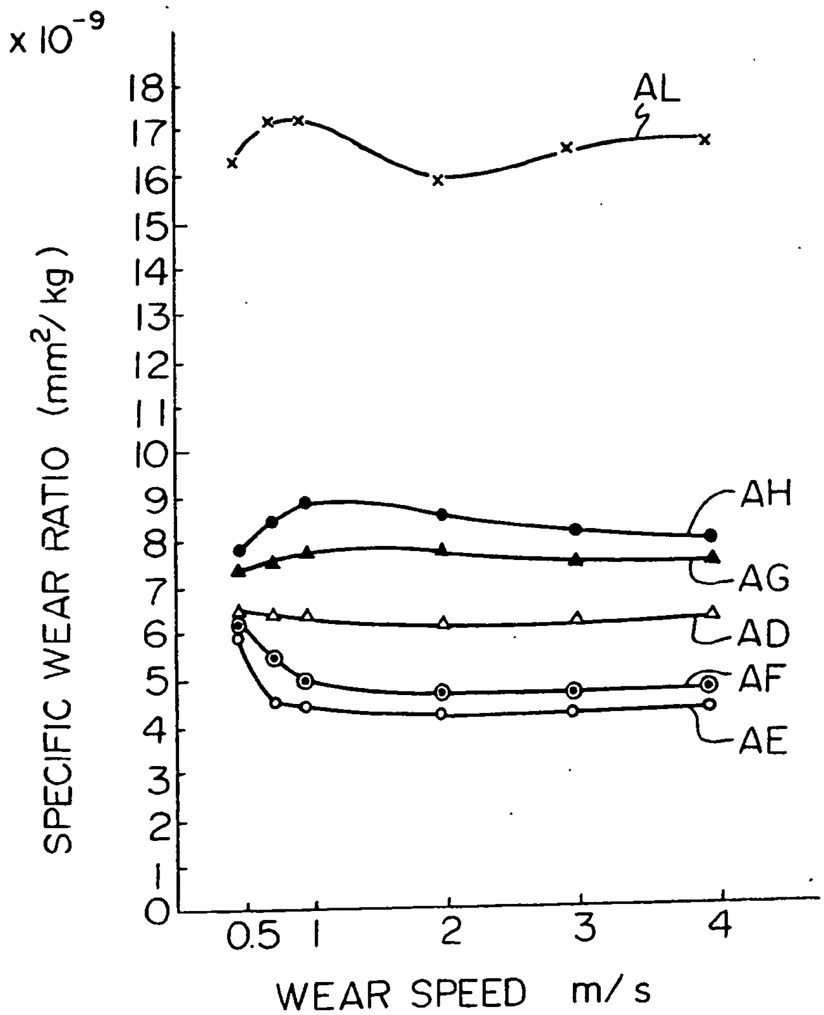

x 10^{-9}
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
SPECIFIC WEAR RATIO (mm^2/ kg)
AL
AH
AG
AD
AF
AE
0.5
1
2
3
4
WEAR SPEED m/ s

Fig. 24A

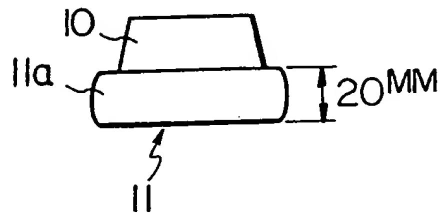


Fig. 24B

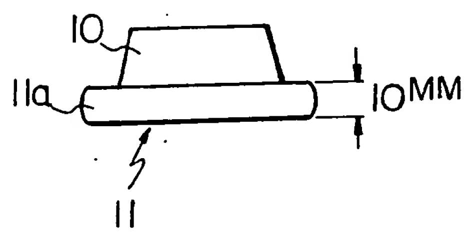
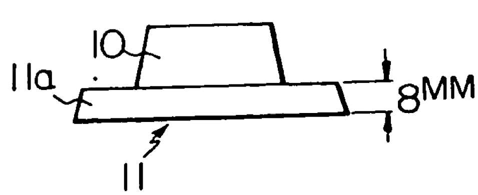


Fig. 24C



SPECIFICATION

A cast bar of an aluminum alloy for wrought products, having improved mechanical properties and workability, as well as process for producing the same

FIELD OF THE INVENTION

The present invention relates to an aluminum alloy and a process for producing the same. More particularly, the present invention relates to an aluminum alloy having improved mechanical properties and workability and a process for producing the same.

In the AA (Aluminum Association) standard 2000, 5000 and 4000 series aluminum alloys, which have been commercially used for wrought products, are as follows: the major alloying component of AA 2000 series is copper, the major alloying component of AA 5000 series is magnesium, and the major alloying component of AA 4000 series is silicon.

As is well-known, because of high specific tenacity, i.e. high strength per unit weight, high impact resistance and high fatigue strength, aluminum base alloys for wrought products according to the above-mentioned standard have been widely used in the production of parts for automobiles and aircraft and various other machinery and apparatus. The above-mentioned series alloys for wrought products can be generally converted into forgings by using either an open die forging process or a die forging process. In the case of the open die forging process to be intended for producing large-sized forgings, it is usual that billets having a diameter of from 150 to 300 mm which are produced by a continuous casting method or a semicontinuous casting method are used. Large diameter billets, which have been conventionally used as a starting material for producing large-sized forgings, exhibit a significantly non-uniform cast structure throughout the cross-sectional area thereof. Particularly, the cast structure of the peripheral portion is substantially different from that of the center portion of the billets. For this reason, the mechanical properties of the billet are variable in different portions of the cross-sectional area of the billets. In addition, there is a possibility that such billets possess defects, such as pinholes, segregation, microshrinkage or microcracking. Accordingly, in order to produce forgings having satisfactory mechanical properties, it is not only necessary to select non-defective billets after being inspected throughly, but it is also necessary to subject the billets to a repeated forging operation to completely eliminate the above-mentioned defects and nonuniform cast structure during the forging process. Accordingly, the production of large-sized forgings from the conventional billets requires a long period of time and much labor.

On the other hand, in the case of the die forging process intended for producing small-sized forgings, it is usual that starting material having a small diameter of from 5 to 70 mm is used. The small diameter starting material is generally obtained by producing billets having a diameter of from 150 to 300 mm by a continuous casting method, subjecting the billet to a homogenizing heat treatment at a temperature of from 450 to 600°C over a period of 2 to 20 hours and hot-extruding the heat-treated billet at a temperature of from 350 to 500°C. In this manner, the conventional process for producing the small diameter starting material requires the extrusion step, which results in an increase in the production cost.

In addition, the conventional processes for producing the aluminum alloys for wrought products have the following disadvantages.

(1) The AA 2000 series alloy and AA 5000 series Al–Mg base alloy generally exhibit a high deformation resistance and a low deformability at the extrusion. This feature makes if difficult to set adequate extrusion conditions such as an extrusion speed. If the extrusion conditions are inadequate, the extruded articles have coarse recrystallization grains at the region near the peripheral surface thereof. Microcracks may be generated at and propagated from the boundaries of the recrystallization grains. In addition the rupture of the extruded articles may eventually be caused due to the recrystallization grains and the intergranular crack.

(2) AA 2000 and 5000 series alloys exhibit a high deformation resistance at the extrusion, as described above. When these alloys are subjected to extrusion, a temperature increase by plastic working occurs because of friction between the die and the workpiece. Accordingly, the working temperature is higher at a later stage of one extrusion pass, which results in a change in th properties of th extruded articles along the longitudinal direction of the extruded articles. As a result, forgings produced from such extruded articles exhibit nonuniformity in properties.

(3) When an alloy material is subjected to extrusion working, the deformation degree in the portion near the peripheral surface is different from that in the central portion of the extruded material. As a result, the extruded article shows a differenc in the work structure between these two portions. Particularly, in the case of AA standard 2000 and 5000 series alloys, th extruded articl s exhibit a promin ntly fine work-structure at the portion near the peripheral surface thereof because of its high deformation degre , while the central portion thereof exhibits a coarse work-structure becaus of its low deformation degree. If the extruded articl s having such a nonuniform structure are forged, the fiber structure of resultant forgings is broken up into fragments and exhibit poor fatigue and impact strengths.

(4) When bill ts made of the AA 2000 or 5000 s ries alloys are subjected to the xtrusion k, the crystal grains and precipitates such as intermetallic compounds in the billets are forced to elongate in the extrusion direction.

As a result, the extruded articles have a crystal texture having a particular directional property and are neither isotropic nor homogeneous. For this reasons, the extruded articles must be forged in consideration of the extrusion direction of the billet. However, if a product having a particular shape is to be produced, it is often difficult to apply the forging to the entire parts of the extruded article so as to provide these parts with the optimal directional property. In such a case, the resultant forgings may suffer from cracks and a local deterioration in the mechanical properties including fatigue strength.

As described above, the small diameter material for forgings produced by extrusion possesses inevitable disadvantages due to the extrusion, particularly, the disadvantages that properties of this material are anisotropic and nonhomogeneous. For this reasons, forgings produced from such a material do not always exhibit satisfactory mechanical properties, particularly, high fatigue strength and high impact strength. The small diameter forging material may also be produced by using a continuous cast- or semicontinuous cast-bar. However, in this case, the same problems as those described for the large diameter billet, such as the nonuniform structure or structural defects, arise. Apart from these problems, it is difficult under the present circumstances to produce a small diameter bar having a diameter of 100 mm or less by a continuous casting method on an industrial scale.

The AA 2014 and AA 2017 Al–Cu alloys and AA 7075 Al–Zn–Mg alloys which have been commercially used as a high strength aluminum base alloy for forgings are superior to the AA 4000 series alloy in respect to mechanical strength, while the former alloys are inferior to the latter alloy in respect to the heat- and wear-resistance. The AA 4000 series alloy exhibits excellent heat- and wear-resistances due to the presence of silicon contained therein.

AA 4032 Al–Si–Cu–Mg–Ni alloy for forgings has particularly excellent heat- and wear-resistances. This grade of alloy is however, disadvantageous in that its forgeability is remarkably inferior because nickel is contained in the alloy in an amount of from 0.5 to 1.3% by weight. Also, in the case of AA 4000 series alloy, the forgings are produced by an extrusion followed by forging as is the case with AA 2000 and 5000 series alloys. That is, the forgings are produced by continuously casting a melt of the aluminum alloys into large diameter billets having a diameter of 10 inches or more, subjecting the billets to a high temperature heat treatment, a so-called homogenizing heat treatment, at a temperature of from 450 to 500°C over a period from 2 to 24 hours, and extruding the heat-treated billets thereby to obtain forgings having a desired diameter. In the die forging operation most widely practiced, a round extruded bar having a diameter of 100 mm or less is used. However, this extrusion is highly expensive. In addition, the extruded round bar is not suitable as a forging because the extruded round bar possesses the following disadvantages:

(a) the alloy structure is nonuniform over the cross section perpendicular to the extrusion direction, that is, the crystal grains along the peripheral surface of the extruded articles are liable to b coarsened due to the heat generated by the friction between the surface of the extruded article and the inner surface of the die;

(b) the alloy structure is nonuniform over the cross section along the extrusion direction, (that is, the crystal grains at the final extrusion stage are liable to be made more coarse due to the heat generated during the working operation, as compared with the crystal grain coarsening at the initial extrusion stage), and;

(c) the extruded articles have a directional property in the extrusion direction, that is, extruded articles have undergone a high degree of working in the extrusion direction and acquire a directional property due to the flow of the structure.

Under these circumstances, the inventors have made extensive studies to develop a continuously cast bar of aluminum base alloys for wrought products, particularly, AA 2000, 5000 and 4000 series alloys, so that the bar is; homogeneous in structure; free of defects; exhibits excellent mechanical properties, and; can be subjected, as cast or after a heat treatment, to a working operation such as forging. This operation for producing wrought products must be a single operation, that is the bar is not subjected to any preliminary plastic working having an adverse effect on th properti s of th cast bar, such as the ab v mentioned hot extrusion. As a result, the inventors have found that an adequate combination of th composition of the aluminum base alloy to be cast and th cast structur of the aluminum base alloy produces an aluminum alloy cast bar capable of satisfying the above-mention d requirements and that wh n a melt of an aluminum base alloy having a particular composition is cast under particular conditions, it is possible to produc an aluminum all y cast bar having the desir d structure.

SUMMARY OF THE INVENTION

An object of th present invention is to provid a continuously cast bar of aluminum base

alloys for wrought products equivalent to the AA standard 2000, 5000 and 4000 series, which bar is of a homogeneous structure; is free of defects; exhibits excellent mechanical properties, and; can be subjected, as cast or after heat treatment, to one of the working operations for producing wrought products such as forging, without applying any preliminary plastic working, such as hot extrusion, having an adverse effect on the properties of the cast bar.

Another object of the present invention is to provide a process for producing a continuously cast bar of aluminum base alloys possessing a satisfactory workability, such as excellent forgeability, by selecting an adequate combination of the composition of AA standard 2000, 5000 and 4000 series alloys with cast structure thereof and any selecting the casting conditions.

Still another object of the present invention is to increase the workability of the continuously cast bar produced by the above-mentioned process by subjecting the bar to a heat treatment.

Still another object of the present invention is to provide an aluminum base alloy in cast state, which exhibits mechanical properties equivalent to, because of no directional properties, or, superior to that possessed by the conventional extrusion of aluminum base alloys.

The basic technical concept of the present invention resides in the discovery that, a critical value of the secondary dendrite arm spacing (hereinafter referred to as DAS) and a critical value of the size of second phase particles and/or the grain diameter, which critical values are substantially lower than the DAS, the size of the second phase particles and the grain diameter in the conventional aluminum alloy ingot, are responsible for fine cast structure capable of remarkably enhancing the workability and the mechanical properties of the aluminum base alloys for wrought products having the compositions described hereinbelow.

The process for producing an aluminum base alloy bar according to the present invention is based on the technical concept that, when an aluminum base alloy melt is cast into a smaller diameter bar at a higher casting speed than in the case of the conventional continuous casting method industrially practiced,the resultant bar has a cast structure which is microscopically fine, macroscopically fine, isotropic and free from defects.

In accordance with one aspect of the present invention, there is provided a cast bar of an aluminum base alloy for wrought products (AA standard 2000 series for wrought products), exhibiting high tensile strength, impact strength and fatigue strength, which compirses 2.0 to 9.0 wt% of copper, 0.2 to 1.2 wt% of magnesium, 0.2 to 1.2 wt% of silicon, 0.2 to 0.8 wt% of manganese, and the balance consisting of aluminum and unavoidable impurities and occasionally an optional component(s), and wherein the DAS is not greater than 15 μm, the grain diameter is not greater than 80 μm and the second phase particles comprising intermetallic compounds have a size not greater than 10 μm.

In accordance with another aspect of the present invention, a cast bar of an aluminum base alloy for wrought products of the present invention is characterized by a combination of a particular composition and a particular structure, particularly, relating to a uniform distribution of solute components (solution components) throughout the grain boundaries and the matrix of the crystal grains. More specifically, the present invention provides a cast bar of an aluminum base alloy for wrought products (AA standard 2000 series homogeneous alloy) exhibiting high tensile strength, impact strength and fatigue strength, having the same composition as that of the above-mentiond AA standard 2000 series alloy and wherein the ratio of the concentration (a) of the solute components in the matrix within the crystal grain to the concentration (b) of the solute components in the grain boundaries, i.e. a/b, is not smaller than 0.70.

In accordance with still another aspect of the present invention, there is provided a process for producing a cast bar of an aluminum base alloy for wrought products corresponding to AA standard 2000 series alloy. More specifically, the process comprises preparing a melt of the alloy composition and continuously casting the melt at a solidification speed of not lower than 25°C/sec.

In accordance with still more another aspect of the present invention, there is provided a process for producing a cast bar of an aluminum base alloy corresponding to the AA standard 2000 series homogeneous alloy. More specifically, there is provided a process for producing a cast bar of an aluminum base alloy which compris s preparing a melt f the alloy composition, continuously casting the melt at a solidification speed of not l wer than 25°C/sec, and subjecting th cast bar to a homogenizing heat treatment at a temperature of from 450 to 530°C over a period of from 0.5 to 20 hours.

In accoradance with a further aspect of the present invention, there is provided a cast bar of an aluminum base all y (AA standard 5000 series alloy) comprising 2.0 to 6.0 wt% of magnesium, 0.03 to 0.3 wt% of chromium, and the balance being aluminum and unavoidable impurities, and, occasionally an optional component(s), and wherein, th grain diam ter is not greater than 80 μm, the DAS is not greater then 13 μm, and the size of the second phase particles is not greater than 10 μm.

The above mentioned AA standard 5000 s ries alloy may further contain at least one of th following optional elements select d from the group consisting of: titanium in an amount f

from 0.005 to 0.2 wt%, manganese in an amount not more than 0.5 wt%; zirconium in an amount not more than 0.3 wt%, and tin in an amount not more than 0.5 wt%. The titanium may be partly replaced with boron so that the total amounts of titanium and boron are not more than 0.2 wt%.

In accordance with another aspect of the present invention, a cast bar of an aluminum alloy (AA standard 5000 series homogeneous alloy) has the same composition as that of the above mentioned AA standard 5000 series alloy and wherein the ratio of the concentration (a) of the solute components in the matrix of the crystal grain to the concentration (b) of the solute components in the grain boundaries, i.e., a/b, is not greater than 0.70.

In accordance with another aspect of the present invention, there is provided a process for producing a cast bar of the above-mentioned AA standard 5000 series alloy. More specifically, the process comprises preparing a melt of the above-mentioned alloy composition and continuously casting the melt at a soldification speed of not lower than 15°C/sec.

In accordance with another aspect of the present invention, there is provided a process for producing a cast bar of an aluminum alloy corresponding to the above-mentioned AA standard 5000 series homogeneous alloy. More particularly, there is provided a process for producing a cast bar of an aluminum alloy which comprises preparing a melt of the alloy composition, continuously casting the melt at a solidification speed of 15°C/sec or higher, and subjecting the cast bar to a homogenizing heat treatment at a temperature of from 450 to 500°C over a period of 1 to 24 hours.

In accordance with a further aspect of the present invention, there is provided a cast bar of an aluminum base alloy for forgings (AA standard 4000 series Al-Si-Mg alloy) exhibiting excellent workability, wear and heat-resistances, which comprise 4 to 12 wt% of silicon 0.6 to 1.3 wt% of magnesium and the balance consisting essentially of aluminum and unavoidable impurities and occasionally an optional component, and which has a fine cast structure, in which the primary crystals have a size of not greater than 50 μm, preferably, not greater than 25 μm, the intermetallic compounds of second phase particles have a size of not greater than 15 μm and the DAS is not greater than 20 μm. This alloy may further contain as an optional component, at least one member selected from the group consisting of 0.05 to 0.2 wt% of titanium, 0.02, to 0.2 wt% of vanadium, 0.01 to 0.1 wt% of lithium, 0.001 to 0.05 wt% of beryllium, 0.1 to 0.5 wt% of chromium and 0.02 to 0.2 wt% of zierconium, with the proviso that the total of th s optional components is not more than 1.2 wt%.

In accordance with another aspect of the present invention, there is provided a cast bar of an aluminum base alloy (AA standard 4000 series Al-Si-Cu-Mg alloy) exhibiting excellent workability, wear- and heat-resistance, which comprises 2 to 12 wt% of silicon, 1.5 to 5.0 wt% of copper and, 0.8 to 1.3 wt% of magnesium. This alloy may further contain as an optional component, at least one member selected from the group consisting of 0.05 to 0.2 wt% of titanium, 0.02 to 0.2 wt% of vanadium, 0.01 to 0.1 wt% of lithium, 0.001 to 0.05 wt% of beryllium, 0.1 to 0.5 wt% of chromium and 0.02 to 0.2 wt% zirconium, with the proviso that the sum of these optional components is not greater than 1.2 wt%, and the balance consisting essentially of aluminum and unavoidable impurities, and which has a fine cast structure, in which the primary crystals have a size of not greater than 50 μm, preferably, not greater than 25 μm, the intermetallic compounds have a size of not greater than 15 μm, and the DAS is not gr ater than 20 μm.

In accordance with a still another aspect of the present invention, there is provided a process for producing a cast bar of an aluminum base alloy which comprises preparing a melt of the AA standard 4000 series Al-Si-Mg alloy, and continuously casting the melt at a solidification sp ed of not lower than 25°C/sec.

In accordance with a still more another aspect of the present invention, there is provided a process for producing a cast bar of an aluminum base alloy which comprises preparing a melt of the AA standard 4000 series Al-Si-Cu-Mg alloy and continuously casting the melt at a solidification speed of not lower than 25°C/sec.

In accordance with a further aspect of the present invention, the above-mentioned AA standard 4000 series Al-Si-Mg alloy and Al-Si-Cu-Mg alloy are characterized in that the area occupied by the second phase particles comprising the primary crystals and at least on member selected from intermetallic compounds such as Al-Cu, Al-Si, Mg-Si, Al-Mn-Fe, Al-Fe-Si and Al-Cu-Mg compounds, does not xceed 25% at any r gion of th examined cross section of the cast bar, and the primary crystals have a grain size of n t exceeding 25 μm and the intermetallic compounds have a size of not exceeding 15 μm.

The cast structure of the aluminum base alloy cast bars of the present invention is fine, homogeneous and isotropic from the central portion to the peripheral surface thr ughout the cross sections thereof taken in any direction. In addition, the aluminum alloy cast bars exhibit high tensil strength, impact strength and fatique str ngth, and, further, even if they may contain a large amount of alloying elements, exhibit an xcellent workability. The aluminum alloy cast bars of the present invention can be subjected directly to plastic w rkings such as

forging or mechanical workings such as machining without applying a preliminary working, such as extrusion. This feature makes it possible to produce various aluminum alloy parts at low cost and to eliminate adverse effects on the parts due to a preliminary working such as extrusion working. Forgings or other wrought products, therefore, exhibit excellent properties and are produced at a low cost. Also, in accordance with the process of the present invention, aluminum base alloy for wrought products exhibiting the above-mentioned excellent properties can be simply and easily obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross sectional microscope view of a cast bar consisting of one of AA standard 2000 series aluminum alloy and being produced by casting at a solidification speed of 25°C/sec;

Figure 2 is the same view as in Fig. 1, except that the solidification speed was 0.5°C/sec;

Figure 3 is a cross sectional microscope view of a cast bar consisting of one of AA standard 5000 series aluminum alloy and being produced by casting at a solidification speed of 15°C/sec;

Figure 4 is the same view as in Fig. 3, except that the solidification speed was 0.1°C/sec;

Figure 5 is a cross sectional microscope view of a cast bar consisting of an AA standard 4000 series alloys and being produced by casting at a solidification speed of 30°C/sec;

Figure 6 is the same view as in Fig. 5, except that the solidification speed was 30°C/sec;

Figure 7 is a graph showing a tensile strength and an elongation versus sampling positions of a specimen in Example 1;

Figures 8A and 8B perspective views of a wedge specimen and an illustration showing a method for testing, using the wedge specimen, respectively;

Figure 9 is a graph showing a limitative working degree versus solidification speed of a wedge specimen from Example 2, the limitative working degree being a working degree at which forging cracks occur;

Figure 10 is a graph showing a deformation resistance and a deformability versus solidification speed of a specimen in Example 2;

Figure 11 is a graph showing a DAS versus solidification speed of each of alloy ingots A, B and C in Example 3;

Figure 12 is a graph showing a tensile strength and an elongation versus solidification speed of an alloy B in Example 3;

Figure 13 is a graph showing an impact value and a reduction of area versus solidification speed of an alloy B in Example 3;

Figure 14 is a graph showing a fatique strength in terms of test load of a specimen in Example 4;

Figure 15 is a graph showing a tensile strength and an elongation versus the sampling positions of a specimen from Example 5;

Figure 16 is a graph showing a limitative working degree versus solidification speed of wedge specimens in Example 6;

Figure 17 is a graph showing a deformation resistance and a deformability versus solidification speed of specimens in Example 6;

Figure 18 is a graph showing a DAS versus solidification speed of each of alloys D, E and F in Example 7;

Figure 19 is a graph showing a tensile strength and an elongation versus solidification speed of the alloy E in Example 7;

Figure 20 is a graph showing an impact value and a reduction of area versus solidification speed of the E in Example 7;

Figure 21 is a graph showing an effect of the size of a second phase particles on a limitative working degree of aluminum ingots which were forged at a temperature ranging from 200 and 450°C;

Figure 22 shows a wear resistance in terms of a specific wear ratio of the present alloy in comparison to that of several conventional alloys;

Figure 23 shows a tensile strength at a t mperature of from ambient t mperature to 400°C of the present alloy in comparison to the conventional alloy, and;

Figures 24A, 24B and 24C each are an illustration showing an upsetting test.

DETAILED DESCRIPTION OF THE INVENTION

The term "working" as used herein is not always limited to forging, and it is intended to include other plastic workings such as rolling, drawing, wire drawing and extrusion and also machining such as cutting. Accordingly, the aluminum base alloys for wrought products of the present invention can be subjected to various plastic workings and machining. It is to be und rstood that the term "continuous casting" as used herein is intended to include not only a so-called complet d continuous casting, but also a semi-continuous casting for producing a

certain length of cast articles.

The term "secondary dendrite" as used herein is used in an ordinary sense in the field of metallography. The secondary dendrite is distinguished from the dendrite cell meaning a primary dendrite.

The fine structure of AA standard 2000 series alloy for wrought products according to the present invention is explained first. This alloy should have the above-mentioned composition and a fine cast structure, such that the grain diameter is not greater than 80 μm, the DAS is not greater than 15 μm and the second phase particles comprising intermetallic compounds have size not exceeding 10 μm.

The intermetallic compounds constituting the second phase particles include Al–Cu, Mg–Si, Al–Mn–Fe, Al–Fe–Si compounds and the like.

When the grain diameter, the DAS and the second phase particle size are outside each of the above defined values, even if the composition of the alloy is within the compositional ranges as described hereinafter, the resultant cast bar cannot exhibit desired properties, such as high tensile strength, high fatique strength and high impact strength. In addition, the isotropic macrostructure of the alloy is lost and the macrostructure tends to be inhomogeneous, with the result that the alloy exhibits a poor workability.

The fine structure of AA standard 5000 series alloy for wrought product of the present invention is explained second. This alloy should satisfy conditions such that the grain diameter is not greater than 80 μm, the DAS is not greater than 13 μm and the second phase particles comprising intermetallic compounds have a size of not greater than 10 μm. Thus, this alloy exhibits excellent workability and high tensile strength, impact strength and fatique strength.

The fine structure of the AA standard 4000 series alloy for wrought products of the present invention explained third. This alloy has a cast structure, wherein the DAS is not greater than 20 μm and the size of the second phase particles is not greater than 50 μm. Also, desirably, the area a percentage of the second phase particles comprising primary crystals and one or more intermetallic compounds, composed of Al–Cu, Al–Si, Mg–Si, Al–Mn–Fe, Al–Fe–Si, Al–Cu–Mg and the like is 25% or less at any sectional region of the alloy.

If the area percentage occupied by the second phase particles is more than 25%, the resultant alloy exhibits a remarkably poor forgeability. Also, if the size of the second phase particles is more than 50 μm, the resultant alloy is not only liable to crack during the forging but also has a poor machinability.

The conditions of homogenity of the AA standard 2000 series and 5000 series homogeneous alloys of the present invention may be satisfied, in substitution for the above defined fine structures. Namely, these alloys should have such a structure that the ratio of the concentration (a) of the solute components, such as Cu, Cr, Mg, Si and Mn, in the matrix of the crystal grains to the concentration (b) of the solute components, such as Cu, Mg, Si and Mn, contained in the grain boundaries i.e. a/b, is 0.70 or more. The concentration (b) can be determined by locally applying the X-ray over a specimen across the grain boundaries by emission spectroanalysis or X-ray analysis, and then comparing the detected concentration of the components of the grain boundaries with the detected concentration of the components in the matrix of the crystal grains. In accordance with the present invention, enrichment of the solute components in the grain boundaries is suppressed so as to avoid a reduction in the ductility of the aluminum base alloys. This suppression of the solute component enrichment is effective for attaining the effects equivalent to those obtained by the limitation of the DAS, the grain diameter and the size of the second phase particles.

It is some times difficult to maintained by the control of the solidification speed the macroscopically isotropic property of the cast bars. In such a case, if the cast bars produced by a solidification speed of at least a critical cooling speed is subjected to a homogenizing heat treatment suitable for adjusting the distribution of the solute components so as to obtain a ratio of a/b of at least 0.70, the homogenized bars exhibit almost same desired properties as those attained by the aluminum base alloys for wrought products, having the fine structure. In order to obtain the concentration a ratio of a/b of at least 0.70, the homogenizing heat treatment is carried out at a temperature of from 450 to 530°C over the period of 0.5 to 20 hours for AA standard 2000 series alloy, and at a t mperature of from 450 to 580°C over th period of 1 to 24 hours for AA standard 5000 series all y.

Ideally, not only the limitation of th grain diameter, the DAS and the second phase particle size to the above-mentioned maximum values but also the limitation of the ratio, a/b, to the value of at l ast 0.70 should be satisfied in AA standard 2000 series and 5000 series alloys for wrought products. In this case, the workability and the mechanical properties f the cast bar are further enhanc d as compared in th alloys satisfying grain diameter, DAS and second phase particle size but not the concentration ratio, a/b.

The aluminum alloy bar satisfying the grain diameter, DAS and the second phas particle size can b produced by a continuous casting process wh rein th solidification speed at any site throughout the cross section of the bars is set to at least a critical speed.

The critical solidification speed is 25°C/sec for the AA standard 2000 series alloy, 15°C/s c for the AA standard 5000 series alloy and 25°C/sec, preferably, 30°C/sec for the AA standard 4000 series alloy.

When the solidification speeds are gradually increased from a level much lower than the critical solidification speeds in the production of the AA standard 2000 series, 5000 series and 4000 series alloys for wrought products, the grain diameter, the DAS and the second phase particles of the alloys become extremely small or very fine in the vicinity of the critical solidification speeds, whereby the above-mentioned structure conditions are satisfied. In other words, solidification of at least the critical solidification speeds permits to provide the cast bars with the desired mechanical properties and workability. For this reason, the solidification speeds should be set to values of at least the critical speeds.

The term "solidification speed" as used herein refers to a temperature dropping speed at the interface between the solid phase and the liquid phase of an alloy placed in a continuous casting mold. The temperature dropping speed can be experimentally detected, for example, by inserting a thermocouple into the liquid phase from above the mold and determining a change in temperature of the place where the thermocouple comes into a contact with the solid phase.

In the continuous casting production of the aluminum base alloys for wrought products of the present invention, a conventional float type continuous casting process is difficult to apply for the production of bars having a diameter of 100 mm or less. As far as the inventors know, a gas pressure-applying type hot top continuous casting process, which has been proposed in USP No. 4,157,728 is the best process for producing a bar with a small diameter of particularly from 5 to 70 mm. It is however, to be understood that if any continuous casting process other than the process of USP No. 4,157,728 allows to obtain good qualities and solidification speeds greater than the critical solidification speeds, this process can be applied to the processes of the present invention.

The cast bars thus prepared may be subjected directly to plastic working or mechanical working. Alternately, the cast bars may be subjected to a homogenizing heat treatment before being worked on by various procedures. Furthermore, the cast bar may be subjected to a heat treatment such as T_6 treatment before being worked on by various procedures.

The fact that the cast structure of AA standard 2000 series alloy becomes suddenly fine at a solidification speed of about 25°C/sec will be illustrated with reference to Figs. 1 and 2. Fig. 1 shows a microscope view of a structure of an aluminum base alloy bar consisting of 4.5 wt% of Cu, 0.6 wt% of Mg, 0.6 wt% of Si, 0.4 wt% of Mn, 0.01 wt% of Ti and the balance being Al and trace of impurities. The aluminum base alloy was continuously cast at a solidification speed of 25°C/sec into the form of the bar which was cut so as to observe the micro structure of the bar cross section. Fig. 2 shows a microscope view of the same aluminum base alloy bar as in Fig. 1 except that the bar was produced by casting with the solidification speed of 0.5°C/sec. As being apparent from Fig. 1, the granular crystals are uniformly distributed through the structure shown in Fig. 1, the DAS is not greater than 15 μm and all of the second phase particles comprising intermetallic compounds have a size not greater than 10 μm, with regard to the alloy cast at tho high solidification speed. In contrast, as being apparent from Fig. 2, the DAS is greater than 15 μm, the second phase particles comprising intermetallic compounds are significantly coarse with regard to the alloy cast at the low solidification speed.

Fig. 3 shows a microscope view of a structure of an aluminum alloy bar consisting of 3.0 wt% of Mg, 0.15 wt% of Cr, 0.01 wt% of Ti, 0.2 wt% of Mn and the balance consisting being Al and trace of impurities. The aluminum alloy was cast at a solidification speed of 15°C/sec into the form of a bar which was cut so as to observe the micro structure of the bar cross section. Fig. 4 shows a microscope view of the same aluminum alloy bar as in Fig. 3 except that the bar was produced by casting with the solidification speed of 0.1°C/sec. As being apparent from Fig. 3, the granular crystals are uniformly distributed through the structure shown in Fig. 3, the DAS is not greater than 13 μm and all of the second phase particles comprising intermetallic compounds have a size not greater than 10 μm, with regard to the alloy cast at the high solidification speed. In constract, as being apparent from Fig. 4, the DAS is greater than 13 μm, the second phase particles comprising intermetallic compounds are significantly coars with regard to the all y cast at the low solidification speed.

Fig. 5 shows a micr scope view of a structure of a cast bar consisting of an AA standard 4000 series alloys. The aluminum alloy was cast at a solidification speed of 30°C/sec into the form of a bar which was cut so as to observe the structure of the bar cross section. Fig. 6 shows a microscope view of the same aluminum alloy bar as in Fig. 5 except that the bar was produced by casting with the solidification speed of 3°C/sec. As being apparent from Fig. 5, crystals are uniformly distributed through the structure shown in Fig. 5, the DAS is n t greater than 20 μm, the second phase particl s comprising intermetallic compounds have a size not greater than 15 μm, and, the second phase particl s c mprising primary crystals have a size not greater than 50 μm with regard to the alloy cast at the high solidification speed. In constrast, as b ing apparent from Fig. 6, the DAS is greater than 20 μm, the second phas particles

comprising intermetallic compounds and primary crystals are significantly coars with regard to the alloy cast at the low solidification speed.

As a result of our investigations of the relationship between the solidification speed and the properties of the resultant alloy ingot, the lower limit of the solidification speed was found to be 25°C/sec for AA standard 2000 series and 4000 series alloys and 15°C/sec for AA standard 5000 series alloy. It goes without saying that in order to produce an alloy ingot at a high solidification speed, a continuous casting is the most suitable. The most convenient continuous casting process which can be industrially used, today, is a vertical semi-continuous casting process. In order to realize a high solidification speed, for example, 25°C/sec or more, in this vertical semi-continuous casting process, casting a melt into a bar having a small diameter is appropriate. The solidification speed 25°C/sec or more, preferably 30°C/sec or more suitable for the AA standard 4000 series alloy can be realized by determining the diameter of the resultant bar to a small size of from 40 to 100 mm without making any substantial modification in the cooling-water injecting conditions, such as the water temperature, the water flow rate, and the water-injecting position, usually employed in the operation of the process according to USP No. 4,157,728.

The alloy compositions of the present invention will be discussed, below.

First, the reasons for the limitation of the composition of the AA standard 2000 series alloy will be illustrated. If the copper content is less than 2.0 wt%, the resultant bar exhibits an unsatisfactory mechanical strength. If the copper content is more than 9.0 wt%, the copper is not solutionized to a satisfactory extent even by a solution treatment and is precipitated as intermetallic compounds. As a result, the mechanical properties, such as tensile strength, elongation and impact strength, of the cast bar become inferior, which leads to the formation of casting cracks of the resultant bar during a continuous casting operation. However, by establishing a solidification speed of 25°C/sec or higher at any site throughout the solid-liquid interface, it is possible to carry out the continuous casting operation smoothly without causing any casting cracks due to high copper content of up to 9.0 wt%. Since a high cooling speed is maintained uniformly over the bar cross section being cast, the segregation tendency seen in the bar cross section is reduced and the solidification, which is quite similar to an ideal unidirectional solidification, takes place. Such solidification seems to make it possible to increase the maximum copper content, at which no serious copper segregation occurs, as compared with the prior art.

Also, if the magnesium content is less than 0.2 wt%, the resultant cast bar exhibits a poor tensile strength. If the magnesium content is more than 1.2 wt%, the Mg–Si intermetallic compounds are formed, which causes deterioration of elongation and tensile strength of the resultant cast bar. As a result of the intermetallic compounds, a cast bar exhibiting the desired properties, i.e. high fatique strength and high impact strength, cannot be obtained. Also, if the silicon content is less than 0.2 wt%, the resultant alloy is not heat-treatable. On the other hand, a silicon content more than 1.2 wt% causes deterioration of a tensile strength and impact strength of resultant cast bar. A manganese content less than 0.2 wt% is ineffective for obtaining high tensile strength and impact strength. If the manganese content is more than 0.8 wt%, coarse grains are formed, with the result that the structure conditions described above cannot be satisfied, which causes the resultant cast bar to exhibit a poor tensile strength. The aluminum alloy of the present invention may contain, if necessary, titanium. Alternately, the aluminum alloy may contain both titanium and boron, in a total amount of from 0.005 to 0.15 wt%. The titanium or both titanium and boron is effective for further refining the crystal grains and thus, for attaining more excellent mechanical properties.

Secondly, the reasons for the limitation of the composition of the AA standard series 5000 alloy will be illustrated. If the magnesium content is less than 2.0 wt%, the resultant cast bar is unsatisfactory in mechanical properties. Also, a magnesium content more than 6.0 wt% has an adv rse effect on the hot workability of the resultant cast bar and has a possibility of causing the str ss corrosion cracking. A chromium content less than 0.03 wt% is ineffective for preventing the resultant cast bar from undergoing stress corrosion cracking. Also, a chromium content more than 0.3 wt% results in the formation of macrosized intermetallic compounds which have an adverse effect on th mechanical prop rties and th workability of th resultant cast bar.

If necessary, titanium in an amount of from 0.005 t 0.2 wt% may b added to the AA standard 5000 series alloy for the purpose f refining the crystal grains. Titanium may be partly replaced with boron. In this case, a total amount of titanium plus boron must be 0.2 wt% or l ss. Mangan se is ffective f r preventing stress corrosion cracking. However, the manganes cont nt more than 0.5 wt% results in the formation of macro-sized intermetallic comp unds which are detrimental to the mechanical properties and the workability. Zirconium is partially solutionized and contributes to the strengthening of the alloy matrix. The other portion of zirconium reacts with magnesium to form the Mg_2Zr intermetallic compounds which are effective for imparting a free cutting property t the resultant cast bar. The solubility of tin is low and, instead, tin reacts with magnesium to form the Mg_2Sn intermetallic compounds which are

effective for enchancing the free cutting of the resultant cast bar.

The compositon ranges of the AA standard 4000 series alloy will be illustrated, below.

In the case of the AA standard 4000 series Al–Si–Mg alloy, silicon is not only effective for strengthening the alloy matrix, but also interacts with aluminum to form an Al–Si eutectic which is effective for increasing the wear resistance and the corrosion resistance in an oxidizing atmosphere. If the silicon content is less than 4 wt%, the resultant cast bar is unsatisfactory in wear resistance. A silicon content greater than 12 wt% results in an increase in the silicon primary crystals which are effective for increasing the wear resistance but detrimental to the tensile strength. The silicon content is preferably in the range of from 6 to 10 wt%.

Magnesium is not only solutionized in aluminum to strengthen the alloy matrix, but also reacts with silicon to from the Mg_2Si intermetallic compounds which contribute to enhancement of the tensile strength and the wear resistance of the cast bar. However, if the magnesium content is less than 0.6 wt%, the contribution of the intermetallic compounds to the tensile strength and wear resistance is unsatisfactory. Also, if the magnesium content is more than 1.3 wt%, the resultant alloy becomes brittle. Accordingly, it is necessary that the silicon content and the magnesium content be in a range of from 4 to 12 wt% and 0.6 to 1.3 wt%, respectively.

In the above-mentioned AA standard series 4000 Al–Si–Cu–Mg alloy, copper is essential for imparting a heat treatable property and high tensile strength to the resultant cast bar. However, if the copper content less than 1.5 wt%, the resultant cast bar exhibits an unsatisfactory toughness. A copper content exceeding 5.0 wt% results in a deterioration in the workability of the resultant cast bar. Silicon has the same effects as those described for the AA standard series 4000 Al–Si–Mg alloy. In addition, silicon is effective for mitigating the cracking during the forging of the resultant cast bar and the porosity of the cast bar. Further, silicon reacts with magnesium to form the Mg_2Si intermetallic compounds which enhaces the heat treatable property of the alloy. However, if the silicon content is less than 2.0 wt%, the desired effects cannot be attained. Also, a silicon content exceeding 12 wt% is effective for increasing the wear resistance but is detrimental to the forgeability and the machinability of the cast bar. Magnesium enhances the strength of the alloy matrix, and the heat treatable property and the wear resistance of the alloy. However, a magnesium content less than 0.8 wt% is ineffective for attaining the these effects. On the other hand, if the magnesium content is greater than 1.3 wt%, the resultant cast bar becomes brittle and exhibits a poor workabilty.

In the AA standard 4000 series Al–Si–Cu–Mg alloys with an optional components particularly the heat resistance and machinability are enhaced by the optional element (A).

In summary, the above described compositions and structure conditions, i.e. grain diameter, the DAS and the second phase particles which are intermetallic compounds composed of, for example Mg–Si, Al–Mn–Fe and Al–Fe–Si and occasionally silicon primary crystals make it possible to produce a cast bar exhibiting high tensile strength, fatique strength and impact strength as well as fine and isotropic structures. The cast bar, which is subjected to a plastic working e.g. forging, and is usually referred to as an ingot or billet, and the cast bar, which is directly subjected to machining according to one of the features of the present invention, possess excellent workabilty.

The wrought products produced by using the cast bar of the present invention are free from undesirable effects of the conventional primary working of the conventional cast bars. The cast bars of AA standard 4000 series alloys according to the present invention are suitable for forginings used as components of a compressor, a vehicle, an air plane and the like.

The present invention will be further illustrated by the examples set forth below, which are provided for the purpose of illustration and should not be interpreted as in any way limiting the scope of the present invention.

Example 1

Run No. 1 (invention)

An aluminum alloy melt comprising 4.7 wt% of copper, 0.7 wt% of silicon, 0.6 wt% of manganese, 0.5 wt% of magnesium, 0.015 wt% of titanium and boron, and the balance consisting essentially of aluminum was prepared and the melt was subjected to a hot top continuous casting process at a solidification speed of 25°C/sec, thereby to produce a round bar having a diameter of 53 mm. The gas pressure was applied to the molten metal body being cast as described in USP No. 4,157,728.

Run No. 2 (control)

The same procedures as those described in Run No. 1 wer repeated, except that a solidificaton speed of 0.15°C/sec was used.

Run No. 3 (control)

The same procedures as those described in Run No. 1 wer repeated, except that a solidification speed of 3°C/sec was used.

From each of the round bars obtained by Run Nos. 1, 2 and 3, sp cimens were cut out along the longitudinal direction of the bars at varying distances from the outer periphery thereof. Each of the specimens was heated at a temperature of 505°C for 6 hours and, then, cooled in hot water. Thereafter, the specimens were aged at a temperature of 170°C for 8 hours to produce a so-called T_6 material. The tensile strength and elongation at normal temperature of the specimens were determined and the results are shown in Fig. 7. In Fig. 7, the cross symbol X denotes a specimen from Run No. 1 (25°C/sec), the black circle symbol denotes a specimen from Run No. 2 (0.15°C/sec) and the circle symbol O denotes a specimen from Run No. 3 (3°C/sec). It is apparent from Fig. 7 that in the case of solidification speeds of 0.15°C/sec and 3°C/sec, a considerable scattering of tensile strength and elongation is noted between the outer periphery portion and the central portion. In the case of the solidification speed of 25°C/sec, there is little scattering in both tensile strength and elongation between the outer periphery and the central portions, which suggests almost homogeneous properties of the cast bar from the outer periphery to the central portions. Also, the DAS, the second phase particle size and the ratio a/b of solute concentration within the matrix of the grain to solute concentration in the grain boundary of the ingot bar obtained by Run Nos. 1, 2 and 3 were determined. The results are shown in Table 1.

Table 1

	Solidification speed °C/sec	DAS µm	Size of secondary phase particles µm	solute concentration ratio a/b %
Run No.2	0.15	40	21	40
Run No.3	3	25	16	55
Run No.1	25	12	8	75

As is apparent from Table 1, in the case of the solidification speed of 25°C/sec, both DAS and second phase particles are fine-sized and the ratio of the solute component concentration (a) to the solute component concentration (b), hereinafter referred to as the solute concentration ratio a/b, is high, while in the case of solidification speeds of 0.15°C/sec and 3°C/sec, both DAS and second phase particles are significantly coarse and the solute concentration ratio a/b, is low. In view of these results and the test results shown in Fig. 7, it is apparent that the structure factors have a great influence on the tensile strength and the elongation of the cast bar.

Example 2

An alloy melt comprising 4.5 wt% of copper, 0.6 wt% of silicon, 0.6 wt% of magnesium, 0.8 wt% of manganese, 0.015 wt% of titanium and the balance consisting essentially of aluminum was prepared, and the melt was cast into a round bar having a diameter of 78 mm by means of a hot top continuous casting process. The gas pressure was applied to the molten metal body being cast as described in USP No. 4,157,728. This casting is hereinafter referred to as the gas-pressure applying type hot top continuous casting. The solidification speed was vari d between 5 and 80°C/sec. The bar was homogenized at a temperature of 505°C for 8 hours to produce test specimens.

W dge specimens as shown in Fig. 8A were cut out from each of the test specimens. The wedge specimens were hot-forged at a temperature of 300, 400 and 450°C, respectively, thereby to determine a limitative working degree at which forging cracks were generated on the specimens.

The wedge test was carried out according to a testing procedure described in "Metal Plastic Working", (in Japanese) Kenzo Kato, published by Maruzen Co. Ltd. In this testing procedure, a specimen in the form of a wedge as shown in Fig. 8A is plac d on a plat n 2 as sh wn in Fig. 8B. Then, a 1/2 ton hammer 3 was struck on the wedg specimen 4. Th working limit is determined on the basis of the crack of the specimen 4 gen rated aft r the f rging operation. This procedure is very suitable and r liable for evaluating th forgeability of a material.

The test results are shown in Fig. 9. Th obliquely lin region of Fig. 9 above the polygonal lines indicates the levels of forging temperature and wedge-shaped reduction ratio allowing the forging without cracks. It is apparent from Fig. 9 that the limitative working degree is increased as th forging temperature is increased. Also, when the solidification speed is high the limitative working degre is high and forging cracks are difficult to occur at any forging temperature. Particularly, the limitative working degree is remarkably increased wh n the solidification speed is increased to about 25°C/sec. This fact corresponds to an abrupt chang in structure at the

solidification speed of about 25°C/sec as described hereinabove. In addition, in rd r t evaluate workability by general hot working including forging and rolling of the cast bars produced at various solidification speeds, the testing material was subjected to a hot torsion test (cf. for example, "Light Metal," Horiuchi et al, (in Japanese) Vol. 20, No. 5) to determine the deformation resistance and the deformability thereof. The results are shown in Fig. 10. As is apparent from Fig. 10, the deformation resistance change depending on the solidification speed increase displays an abrupt decrease at about 25°C/sec and the deformability change depending on the solidification speed displays an abrupt increase at a solidification speed of about 25°C/sec. In view of these results, it is clear that workability of the cast bars according to the present invention is excellent.

Example 3

A alloy melt comprising 2.3 wt% of copper, 0.3 wt% of magnesium, 0.3 wt% of silicon, 0.2 wt% of manganese, 0.02 wt% of titanium and the balance consisting essentially of aluminum (which alloy is referred to as alloy A), alloy melt comprising 4.5 wt% of copper, 0.6 wt% of magnesium, 0.7 wt% of silicon, 0.6 wt% of manganese, 0.01 wt% of titanium and the balance consisting essentially of aluminum (which alloy is referred to as alloy B) and an alloy melt comprising 8.7 wt% of copper 1.0 wt% of magnesium, 1.0 wt% of silicon, 0.7 wt% of manganese, 0.015 wt% of total of titanium and boron and the balance consisting essentially of aluminum (which alloy is referred to as alloy C) were separately prepared. Each of these melts was cast into a round bar having a diameter of 62 mm by means of a gas-pressure applying type hot top continuous casting process at a solidification speed varying between about 6 to about 80°C/sec. The master alloy comprising 5 wt% of titanium, 0.7 wt% of boron and the balance consisting essentially of aluminum was added into the melt of the alloy C so as to incorporate titanium and boron.

The DAS of each of the round bars prepared above was is shown in Fig. 11.

As is clearly shown in Fig. 11, the DAS change of each of the alloys A, B and C depending on the solidification speed increase displays a prominent decrease at the solidification speed up to about 25°C/sec, and DAS assumed an almost constant value of about 6 μm at a solidification speed above 25°C/sec which is a critical solidification speed. This clearly indicates that a solidification speed of 25°C/sec is significant for the fine structure of the AA standard 2000 series alloy according to the present invention, that is, 25°C/sec is a critical solidification speed at which the structure of such alloy becomes fine.

In addition, as a representative example of the above-mentioned three alloys, the alloy B was cast at various solidification speeds into the bars and the tensile strength and elongation of the bars were measured. The results are shown in Fig. 12. It was confirmed from Fig. 12 taking into consideration Fig. 11, that both tensile strength and elongation are increased with the increase in the DAS values. Particularly, an increase in elongation is outstandingly shown. Furthermore, the cast bars produced from the alloy B at various solidification speeds were subjected to an impact test and a drawing test. The results are shown in Fig. 13. it was also confirmed that the solidification speed of 25°C/sec causes a prominent increase of the mechanical properties, i.e., impact value and the reduction of area.

Example 4

Run No. 4 (invention)

An alloy melt comprising 4.0 wt% of copper, 0.2 wt% of silicon, 0.6 wt% of magnesuim, 0.6 wt% of manganese, 0.01 wt% of titanium and the balance consisting essentially of aluminum was prepared, and cast into a round bar having a diameter of 35 mm. The casting was carried out by the gas-pressure applying type hot top continuous casting and the solidification speed was 30°C/sec. The bar was forged into a connecting rod by a conventional hot forging. The connecting rod was heat-treated at a temperature of 505°C for 2 hours, and, then, water-cooled, for the purpose of solution treatment. Thereafter, the connecting rod was aged at room temperature (T_4 treatment) for two days. The resultant material in the form of the connecting rod was subjected to a fatigue test.

Run No. 5 (control)

An alloy melt having the same composition as that of Run No. 4 was cast by a conventional direct chill-casting method. The obtain d cast bar was extruded at an extrusion ratio of 40, thereby to produce an extruded bar having a diameter of 35 mm. The extruded bar was hot forged, solutionized and was subject to a T_4 treatment successively, under the same conditions as those described in Run No. 4. A fatigue test was carried out on the r sultant bar.

The results of the fatigue tests carried out in Run Nos. 4 and 5 are shown in Fig. 14. Since the str ss levels in the connecting rod are locally varied within the planes across the c nnecting rod, the ordinate axis of Fig. 14 indicates not the stress but test load. It is clear from Fig. 14 that the forged material produced by Run No. 4 exhibits a remarkably excellent fatigue strength

as compared with the forged material produced by Run No. 5. The sup riority of the material of Run No. 4 to the material of Run No. 5 is probably ascribable to the following. The material of Run No. 5 subjected to the forging is an extruded material having a fibrous texture developed during the extrusion, and the fibrous texture is broken up during the forging, with the result that the forged product cannot prossess a normal fibrous texture, while the material of Run No. 4 subjected to the forging is a cast bar having a homogeneous internal structure and a macroscopically isotropic property, with the result that a normal fibrous structure is formed at any direction of forging force applied to the production of the connecting rod.

Example 5

Run No. 6 (invention)

An aluminum alloy melt comprising 3.0 wt% of magnesium, 0.25 wt% of chromium, 0.18 wt% of iron, 0.15 wt% of silicon, 0.01 wt% of titanium and the balance consisting essentially of aluminum was prepared and the melt was cast into a round bar having a diameter of 62 mm. The casting was carried out by the gas-pressure applying type hot top continuous casting and the solidification speed was 15°C/sec.

Run No. 7 (control)

The same procedures as those described in Run No. 6 were repeated, except that a solidification speed of 0.10°C/sec was used.

Run No. 8 (control)

The same procedures as those described in Run No. 6 were repeated, except that a solidification speed of 3°C/sec was used.

From each of the round bars obtained by Run Nos. 6, 7 and 8, specimens were cut out along the longitudinal direction of the bars at varying distances from the outer periphery. Each of the specimens was homogenized at a temperature of 525°C for 6 hours. Then, the tensile strength and the elongation of the specimens were determined at normal temperature. The results are shown in Fig. 15. In Fig. 15, the symbol "X" denotes a specimen from Run No. 6 (15°C/sec), the symbol "●" denotes a specimen from Run No. 7 (0.10°C/sec) and the symbol "O" denotes a specimen from Run No. 8 (3°C/sec). As is apparent from Fig. 15, in the case of solidification speeds of 0.10°C/sec and 3°C/sec, a considerable scattering of tensile strength and elogation is noted between the outer periphery and central portions. In the case of a solidification speed of 15°C/sec, there is little scattering in both tensile strength and elongation between the outer periphery and central portions. This suggests an almost uniform property of the cast bar from the outer periphery to central portions. Also, the DAS, the second phase particle size and the solute concentration ratio a/b of the case bar obtained by Run Nos. 6, 7 and 8 were determined. The results are shown in Table 2.

Table 2

	Solidification Speed °C/sec	DAS μm	Size of secondary phase particle μm	Solute concentration ratio a/b %
Run No. 7	0.10	35	20	38
Run No. 8	3	22	14	52
Run No. 6	15	13	7	73

As is apparent from Table 2, in the case of a solidification speed of 15°C/sec, both DAS and second phase particles are fine-sized and the solute concentration ratio a/b is high, while in the case of solidificaton speeds of 0.10°C/sec and 3°C/sec, both DAS and second phase particles are significantly coarse and the solute concentration ratio a/b is low. In view of these results and the test results shown in Fig. 14, it is clear that these structure factors have a great influence on the tensile str ngth and the elongation of the bar.

Example 6

An alloy melt comprising 5.8 wt% of magnesium, 0.20 wt% of chromium, 0.20 wt% of mangan se, 0.013 wt% of total of titanium and b ron and the balance consisting essentially of aluminum was prepared, and was cast into a round bar having a diam ter of 78 mm.

The casting was carri d out by the gas-pressure applying type hot top continuous casting and the solidificati n speed was varied as shown in Fig. 16. The resultant cast bar was homogenized at a temperature of 530°C for 8 hours to produce test specimens.

A wedge specimen as shown in Fig. 8A was cut out from each test specimen. The wedge

specimen was subjected to a hot-forging operation at a temperature of 300, 400 and 450°C, respectively, thereby to determine a limitative working degree at which forging cracks were produced on the specimen. The results are shown in Fig. 16. In Fig. 16, the obliquely-lined region above the polygonal lines indicates levels of the working degree, above which forging cracks occur. As is apparent from Fig. 16, the limitative working degree is increased as the forging temperature is increased. Also, in all levels of the forging temperatures, as the solidification speed is increased, the limitative working degree is increased and forging cracks are unlikely to occur. Particularly, the limitative working degree change with the increase in the solidification speed displays a prominent increase at a solidification speed of about 15°C/sec. This fact corresponds to an abrupt change in the structure of a cast bar at a solidification speed of about 15°C/sec as described above.

In addition, in order to evaluate the workability at general hot working including rolling and forging of each test specimen produced at various solidification speeds, the test specimens were subjected to a hot-torsion test according to the same procedures as those used in Example 2 to determine the deformation resistance and the deformability thereof. The results are shown in Fig. 17. As is apparent from Fig. 17, the deformation resistance change with the solidification speed increase displays a remarkable derease at a solidification speed of about 15°C/sec, and the deformability change with the solidification speed increase displays a prominent increase at a solidification speed of about 15°C/sec. In view of these results, it is clear that the cast bar according to the present invention exhibits excellent workability.

Example 7

An alloy melt comprising 2.3 wt% of magnesium, 0.15 wt% of chromium, 0.20 wt% of manganese, 0.015 wt% of titanium and the balance consisting essentially of aluminum (the alloy referred to as alloy D), an melt alloy comprising 3.5 wt% of magnesium, 0.25 wt% of chromium, 0.15 wt% of manganese, 0.012 wt% of titanium and the balance consisting essentially of aluminum (the alloy referred to as alloy E), and an alloy melt comprising 5.8 wt% of magnesium, 0.30 wt% of chromium, 0.01 wt% of manganese, 0.015 wt% of total of titanium and boron and the balance consisting essentially of aluminum (the alloy referred to as alloy F) were separately prepared. Each of these melts were cast into a round bar having a diameter of 53 mm.

The casting was carried out by the gas-pressure applying type hot top continuous casting and the solidification speed was varied as shown in Fig. 18. In preparing the alloy F, the addition of Ti and B to the melt was carried out by using a master alloy comprising 5 wt% of titanium, 0.7 wt% of boron and the balance consisting essentially of aluminum.

The DAS of each of the cast bars prepared above was determined. The results are shown in Fig. 18. As is clearly shown in Fig. 18, the DAS change the alloys D, E and F with the solidification speed increase displays a decrease up to approximately 15°C/sec of the solidification speed, and the DAS assumes an almost constant value at a solidification speed above 15°C/sec which is, therefore, a critical solidification speed. This clearly indicates that a solidification speed of 15°C/sec is significant for the fine structure of an AA standard 5000 series alloy, that is, 15°C/sec is a critical solidification speed at which the structure of the such alloy becomes fine.

In addition, the melt of alloy E was cast into the bars at various solidification speeds and the tensile strength and elongation of the bars were measured. The results are shown in Fig. 19. It was confirmed from Fig. 19 taking into consideration Fig. 18 that both tensile strength and elongation are increased with the increase in correspondance with the DAS values. Particularly, an increase in elongation is outstandingly shown. Furthermore, the cast bars produced from the alloy E at various solidification speeds were subjected to an impact test and a drawing test. The results are shown in Fig. 20. It was also confirmed that the solidification speed of 15°C/sec causes a prominent increase of the mechanical properties, i.e. the impact value and the reduction of area.

Example 8

The forgeability of the AA standard 5000 series alloys with the structure and composition of the present invention will be illustrated.

Ten alloy melts of the Al–Si–Mg type and Al–Cu–Si–Mg type alloys acc rding to the pr sent invention were separately prepared. These ten types of alloys are designated as G, H, I, J, K, L, M, N, O and P, respectively. Each of these melts was cast into a small diameter billet having a dimater of 50 mm by a semi-continuous casting process at a solidification speed of from 26 to 30°C/sec, the resultant billets had a DAS ranging from 8 to 14 μm and an average DAS of 12 μ. Also, the billets had an averange grain diameter of 120 μm.

For comparison purposes with the AA standard 5000 series alloy three melts of AA 2014, 2017 and 4032 alloys, which have widely been used, were subjected to a conventional semi-continuous casting process, thereby to produce billets having a diameter of 8 inches. The billets

were homogenized and, then, extruded into bars having a diameter of 30 mm. Th xtruded bars were used as starting material for forging.

Each of the billets and the extruded bars were machined to manufacture specimens for wedge test as shown in Fig. 8A. The results are shown in Table 3, together with the alloy compositions and the percentage of an area of the second phase particles. The specimens were forged at a temperature of 200°C. The percentage of an area of the second phase particles was determined according to a voltage integration procedure by using an area analyzer.

Table 3 clearly indicates that the cast bars of the present invention exhibit a limitative working degree similar or superior to that of the extruded bars of the control alloys and thus, is excellent in forgeability. Also, Table 3 shows that the forgeability of the cast bars of the present invention is enhanced as the percentage of an area of the second phase particles in decreased.

Table 3

Alloy	Composition (wt%)									Percentage of area of secondary phase particles (%)	Limitative Working degree (%)
	Si	Cu	Mg	Ti	V	Mn	Be	Cr	Zr		
invention											
G	2.0	–	1.3	0.015	–	–	–	0.2	0.2	6.8	85
H	6.0	–	0.9	0.015	–	–	–	–	–	12.5	83
I	8.0	–	1.0	0.02	–	–	–	–	0.2	14.5	79
J	11.7	–	1.3	0.02	–	–	–	–	–	21.7	70
k	2.0	5.0	0.9	0.015	–	–	–	–	–	12.5	84
L	4.0	4.5	1.0	–	–	–	–	–	–	17.3	83
M	6.0	3.0	1.0	0.015	–	–	–	–	–	19.3	72
N	10.0	2.0	0.7	0.015	–	–	–	–	0.2	20.1	76
O	11.5	2.0	0.9	0.015	–	–	–	–	–	23.2	70
P	11.5	2.0	0.9	0.015	–	–	–	0.3	0.2	24.7	68
Control											
Q	0.6	4.5	0.6	0.01	–	–	0.8	–	–	5.2	69
R	0.4	4.0	0.5	0.01	–	–	0.8	–	–	4.7	83
S	12.0	0.9	1.0	0.01	–	Ni=	1.0	–		23.8	32

Note: K: 2014, L: 2017, M: 4032

Example 9

Melts of four types of the AA standard 5000 series alloys of the present invention were cast into four billets having a DAS different from each other by a semi-continuous casting process at various solidification speeds. The limitative working degree of these billets was determined according to the same procedure as that described in Example 1. Melts of six types of control alloys including a hyper-eutectic Al–Si–Cu–Mg type were cast into six billets having a DAS different from each other using semi-continuous casting process at various solidification speeds. Th limitative working degree of these six billets was determined in the same manner. The solidification speed of the alloys T, U, V and W was 30°C/sec, that of the alloys X and Y was 27°C/sec, and that of the alloys Z, AA, AB and AC was in the range of from 8 to 10°C/sec. As is apparent from Table 4, the forgeability is poor, when the alloy billets have an area percentage of the second phase particles more than 25% or when the alloy billets have DAS of more than 20 μm. Also, although alloys X and Y having a composition outside the present invention were cast at the solidification speed of the present invention, the resultant billets had an area percentage of the second phase particles higher than 25% and thus, extremely poor forgeability.

Table 4

		Composition (wt%)									Area Percentage of second phase particles	DAS	Limitative working degree
	Alloy	Si	Cu	Mg	Ti	V	Mn	Be	Cr	Zr	%	µm	%
This invention	T	6.0	–	0.9	0.015	–	0.2	–	0.2	0.2	13.0	12	82
	U	11.7	–	1.3	0.015	0.4	–	–	–	–	22.0	12	71
	V	4.0	4.5	1.2	0.02	–	–	–	0.2	–	18.0	13	81
	W	11.5	4.0	1.0	0.02	–	–	–	0.2	–	24.0	15	70
Control	X	14.0	3.0	1.0	0.02	–	–	–	–	–	26.5	12	49
	Y	18.0	4.5	0.5	0.02	–	0.1	–	–	–	34.6	13	35
	Z	6.0	–	0.9	0.015	–	0.2	–	0.2	0.2	13.5	22	48
	AA	11.7	–	1.3	0.015	0.4	–	–	–	–	22.3	25	31
	AB	11.5	4.0	1.0	0.02	–	–	–	0.2	–	24.5	24	32
	AC	18.0	4.5	0.5	0.02	–	0.1	–	–	–	35.2	21	27

Example 10

Size of second phase particles including primary silicon crystals of the alloy corresponding to the alloy W described in Table 4 was changed by adding phosphorous, as a refining agent, in an amount of from 0.1 to 30 ppm to the alloy and by varying the solidification speed during the casting operation of the alloy. Fig. 21 shows how the forgeability was influenced by such size. The forgeability is indicated in terms of a limitative working degree at a forging temperature varying from 200 to 450°C. Referring to Fig. 21, it will be understood that, when the size of the second phase particles exceed 50 μm, the forgeability of the alloy ingot is considerably low. The size of the second phase particles has therefore a great influence on the forgeability.

Example 11

In this example, the wear resistance of the alloy of the present invention will be discussed. Before going into the description of the experiment by the present inventors, a general knowledge of a wear-resistant aluminum alloy is described. It is known that an aluminum alloy containing a high content of silicon exhibits a high wear resistance but is inferior in workability. One example of such an alloy is an A 390 alloy comprising 18 wt% of silicon, 45 wt% of copper, 0.5 wt% of magnesium, 0.1 wt% of manganese, 0.02 wt% of titanium and the balance consisting essentially of aluminum.

The inferior workability of the wear-resistant aluminum alloy previously known is coincident with the results given in Table 4. Namely, the alloys falling within the composition range A 390 alloys are indicated in Table 4 as alloys Y and AC both exhibiting remarkably inferior forgeability. This is because, according to opinion of the present inventors, the precipitated amount of the primary silicon crystals is too large to provide the alloy with a satisfactorily low area ratio of the second phase particles.

Now, referring to Table 5, alloys cast by a continuous casting process at a solidification speed of 30°C/sec, and then subjected to a wear resistance test are shown. The resultant cast bars had a DAS of 13 μm, an area ratio of the second phase particles of 18% and an average grain diameter of crystal grains (2–Al) of 120 μm.

Specimens of comparison alloys AC–8A and 99.7% Al were sampled out from the JIS H boat-bottom shaped permanent mold and a specimen of a 4032 alloy was sampled out from a billet having a diameter of 150 mm. The 99.7% Al specimen was tested as cast, while these the AC–8A specimens were solutionized at a temperature of 500°C for 6 hours and, then, cooled in hot water having a temperature of 60°C, and, finally, aged at a temperature of 160°C for 8 hours thereby to produce T6 materials.

The wear resistance of the above mentioned specimens was determined under no lubricant condition by using an Ogoshi type rapid wear testing machine. The results are shown in Fig. 22. Referring to Fig. 22, it is clear that the alloys of the present invention exhibit a much more excellent wear resistance than the conventional typical wear resistant alloys.

Example 12

In this example, the alloy cast bars having the composition given in Table 5 were subjected to a tensile strength testing machine at a temperature of from normal temperature to 400°C.

Table 5

		Composition (wt%)									
	Alloy	Si	Cu	Mg	Ni	Ti	V	Mn	Be	Cr	Zr
This Invention	AD	11.7	–	1.3	–	0.02	–	0.2	–	0.2	0.2
	AE	11.5	4.0	1.0	–	0.02	–	–	–	–	–
	AF	8.0	5.0	1.0	–	0.02	–	–	–	–	–
Comparison	AG	12.0	1.2	1.0	2.0	0.1	–	0.2	0.004	–	–
	AH	12.0	0.9	1.0	1.0	0.01	–	–	–	–	–
	AI		99.7% Al								

Note . . . AG: AC–8A, (JIS H 5202–1971) AH: 4032

The r sults of the t nsil strength test of the alloys shown in Table 5 are shown in Fig. 23. As can be seen in Fig. 23, th present alloy (AD) exhibits a tensile strength exceeding 54 kg/mm^2 at normal temperature and further, it exhibits a much higher tensile strength at elevated temperature than the 4032 alloy which is a typical heat resistant alloy material for forgings. In

this manner, the alloy of the present invention is also very excellent in tensile strength.

Example 13

A aluminum alloy melt comprising 4.0 wt% of copper, 0.6 wt% of magnesium 0.3 wt% silicon, 0.6 wt% mangan, 0.02 wt% titanium, and the balance consisting essentially of Al was prepared, and the melt was cast into a round bar having a diameter of 53 mm. The casting was carried out by the gas-pressure applying hot top continuous casting and the solidification speed was 30°C/sec. For comparison purpose, round bar having a diameter of 53 mm was produced according to the same procedures as those described above, except that the gas pressure was not applied to the cast melt body.

The existence and non existence of the gas-pressure application caused a change in the surface of the cast bars. The influence of the surface on the forgeability was investigated by the method illustrated in Figs. 24A, B and C. That is, a billet 11 having diameter of 53 mm and a length of 140 mm was subjected to upsetting by using a hammer 10, then, the free surface was observed to determine whether or not 11a, cracks were formed. In the case of no application of gas pressure, the resultant cast bar has a lapping surface or a bleb surface and tends to generate cracks on the free surface of the ingot at the first and second steps shown in Figs. 24A and 24B. Microscope inspection of the structure of this cast bar indicated that defects such as cracks, pinholes, and blow holes, were sporadically present in the vicinity of the surface of cast bar. These defects are responsible for the notch effect, causing cracks during forging. In contrast, in the cast of application of gas pressure, the resultant cast bar has a smooth surface and tends not to crack in the three steps shown in Figs. 22A through 22C. In this case, forging without surface defects was obtained.

CLAIMS

1. A cast bar of an aluminum base alloy for wrought products exhibiting high tensile strength, impact resistance and fatigue strength, which comprises 2.0 to 9.0 wt% of copper, 0.2 to 1.2 wt% of magnesium, 0.2 to 1.2 wt% of silicon, 0.2 to 0.8 wt% of manganese, and the balance consisting of aluminum and unavoidable impurities, and wherein the DAS, i.e. secondary dendrite arm spacing, is not greater than 15 μm, the grain diameter is not greater than 80''ιμm and the secondιphase particles comprising intermetallic compounds have a size not greater than 10 μm.

2. A cast bar of an aluminum base alloy for wrought products, exhibiting high tensile strength, impact strength and fatigue strength, which comprises 2.0 to 9.0 wt% of copper, 0.2 to 1.2 wt% of magnesium, 0.2 to 1.2 wt% of silicon, 0.2 to 0.8 wt% of manganese, and the balance consisting of aluminum and unavoidable impurities, and wherein the ratio of the concentration (a) of the solute components in the matrix within the crystal grain to the concentration (b) of the solute components in the grain boundaries, i.e. a/b, is not smaller than 0.70.

3. A cast bar of an aluminum base alloy for wrought products, exhibiting high tensile strength, impact resistance and fatigue strength, comprising 2.0 to 6.0 wt% of magnesium, 0.03 to 0.3 wt% of chromium, and wherein, the grain diameter is not greater than 80 μm, the DAS is not greater than 13 μm and the size of the second phase particles is not greater than 10 μm.

4. A cast bar according to claim 3, wherein said aluminum base alloy further comprises at least one member selected from the group consisting of 0.005 to 0.2 wt% of titanium, a total amount of not more than 0.2 wt% of titanium and boron, 0.5 wt% of manganese, not more than 0.3 wt% of zirconium and not more than 0.5 wt% of tin.

5. A cast bar of an aluminum base alloy for wrought products, exhibiting high tensile strength, impact resistance and fatigue strength, comprising 2.0 to 6.0 wt% of magnesium, and 0.03 to 0.3 wt% of chromium, and wherein the ratio of the concentration (a) of the solute components in the matrix within the crystal grain to the concentration (b) of the solute components in the grain boundaries, i.e. a/b, is not smaller than 0.70.

6. A cast bar according to claim 4 or 5, wherein said alloy further comprises at least one member selected from the group consisting of 0.005 to 0.2 wt% of titanium, not more than 0.5 wt% of manganese, not more than 0.3 wt% of zirconium and not more than 0.5 wt% of tin.

7. A cast bar according to claim 6, wherein said titanium is partly replaced with boron so that the total amount of titanium and boron is not more than 0.2%.

8. A cast bar of an aluminum base alloy for forgings, exhibiting excellent workability and wear- and heat-r sistances, which comprises 4.0 to 12.0 wt% of silicon, 0.6 to 1.3 wt% of magnesium, and which has a fine cast structure, in which the primary crystals hav a size of not greater than 50 μm, pref rably, not greater than 25 μm, the intermetallic compounds of second phase particles hav a size of not greater than 15 μm and the DAS is not greater than 20 μm.

9. A cast bar according to claim 8, wherein said aluminum base alloy further comprises at

l ast one member selected from the group consisting of 0.05 to 0.2 wt% of titanium, 0.02 to 0.2 wt% of vanadium, 0.01 to 0.1 wt% of lithium, 0.001 to 0.05 wt% of beryllium, 0.1 to 0.5 wt% of chromium and 0.02 to 0.2 wt% of zirconium, with the proviso that the total of these members is not greater than 1.2 wt%.

10. A cast bar of an aluminum base alloy for forgings, exhibiting excellent workability and wear- and heat-resistances, which comprises 2 to 12 wt% of silicon, 1.5 to 5.0 wt% of copper, and 0.8 to 1.3 wt% of magnesium, and which has a fine cast structure, in which the primary crystals have a size of not greater than 50 μm, preferably, not greater than 25 μm, the intermetallic compounds have a size of not greater than 15 μm and the DAS is not greater than 20 μm.

11. A cast bar according to claim 10, wherein said aluminum base alloy further comprises, at least one member selected from the group consisting of 0.05 to 0.2 wt% of titanium, 0.02 to 0.2 wt% of vanadium, 0.01 to 0.1 wt% of lithium, 0.001 to 0.05 wt% of beryllium, 0.1 to 0.5 wt% of chromium and 0.02 to 0.2 wt% of zirconium, with the proviso that the sum of these members is not greater than 1.2 wt%.

12. A cast bar according to claim 8 or 11, characterized in that, the area occupied by the second phase particles comprising the primary crystals and intermetallic compounds does not exceed 25% at any region of the examined cross section of the cast bar.

13. A cast bar according to claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or 11, characterized in that the cast bar is for use as machining in the heat treated- or non-heat treated state.

14. A cast bar according to claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or 11, characterized in that the cast bar has a diameter of not greater than 100 mm.

15. A cast bar according to claim 14, characterized in that the cast bar has a diameter of from 5 to 70 mm.

16. A process for producing a cast bar of an aluminum base alloy which comprises 2.0 to 9.0 wt% of copper, 0.2 to 1.2 wt% of magnesium, 0.2 to 1.2 wt% of silicon, 0.2 to 0.8 wt% of manganese, said process comprising preparing a melt of the alloy composition and continuously casting the melt at a solidification speed of not lower than 25°C/sec.

17. A process according to claim 16, further comprising subjecting the cast bar to a homogenizing heat treatment at a temperature of from 450 to 530°C over a period of from 0.5 to 20 hours.

18. A process for producing a cast bar of an aluminum base alloy for forgings, comprising 2.0 to 6.0 wt% of magnesium, and 0.03 to 0.3 wt% of chromium, said process comprises preparing a melt of the alloy composition and continuously casting the melt at a solidification speed of not lower than 15°C/sec.

19. A process according to claim 18 further comprising subjecting the cast bar to a homogenizing treatment at a temperature of from 450 to 580°C over a period of from 1 to 24 hours.

20. A process for producing a cast bar of an aluminum base alloy for forgings, which comprises 4.0 to 12.0 wt% of silicon, 0.6 to 1.3 wt% of magnesium, said process comprises preparing a melt of the alloy composition, and continuously casting the melt at a solidification speed of not lower than 25°C/sec.

21. A process for producing a cast bar of an aluminum base alloy for forgings, exhibiting exc llent workability and wear- and heat-resistances, which comprises 2 to 12 wt% of silicon, 1.5 to 5.0 wt% of copper, and 0.8 to 1.3 wt% of magnesium said process comprises preparing a melt of the alloy composition and continuously casting the melt at a solidification speed of not lower than 25°C/sec.

22. A process for producing the cast bar according to claim 19, wherein the solidification speed is not lower than 35°C/sec.

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